RIVER FORECAST CENTRE BUSINESS TRANSFORMATION
PREMIER'S AWARD
ORGNIZATIONAL EXCELLENCE 2020

# An Overview of the CLEVER Model:
## the real-time flood forecasting system for BC
### — Challenges, science, operations, history and uncertainties

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BC River Forecast Centre, FLNRORD

April 29, 2021

# Contents

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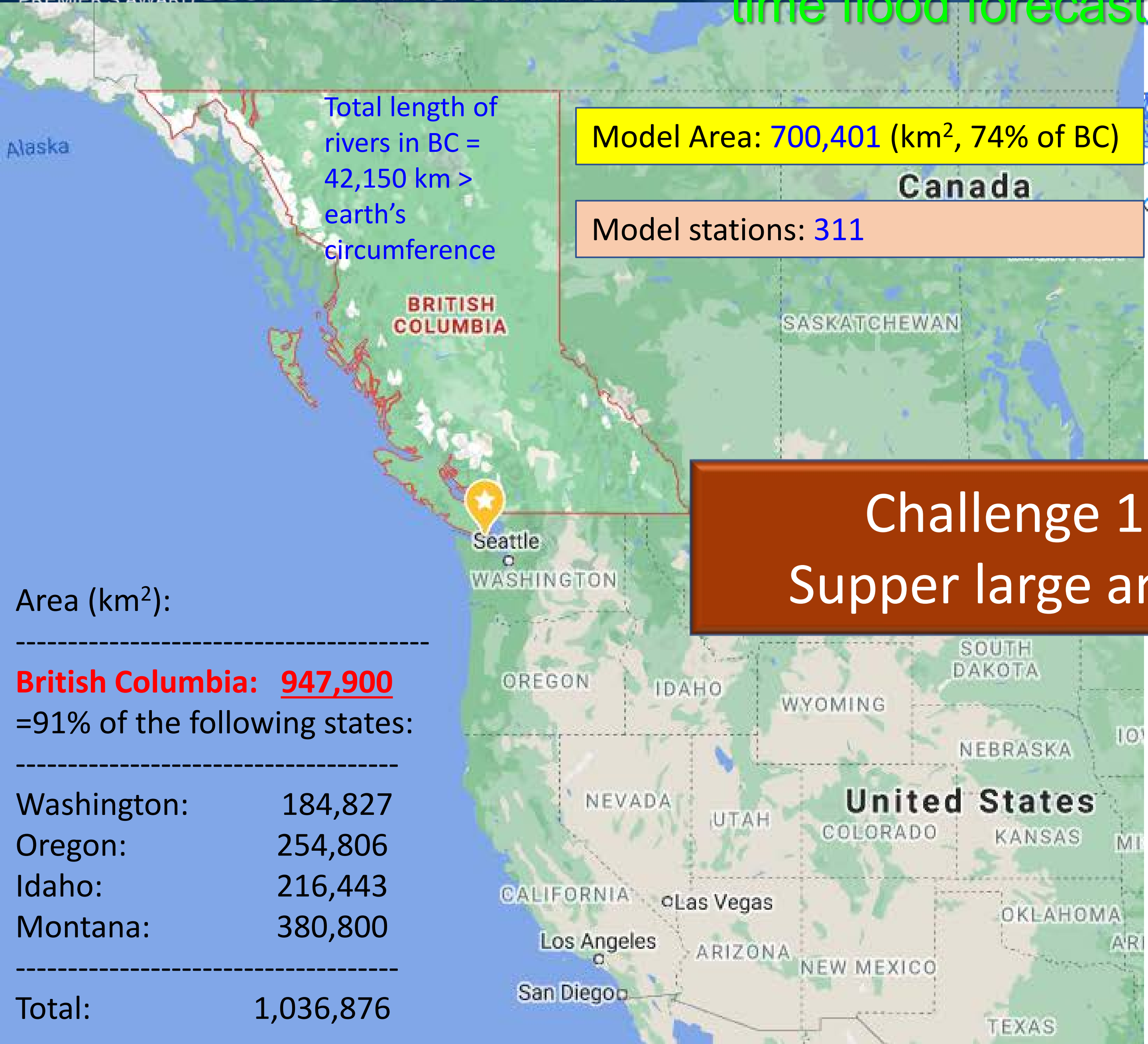
# 1. Why the CLEVER Model – Challenges of real-time flood forecasting in BC




Total length of rivers in BC = 42,150 km > earth's circumference

Model Area: 700,401 (km², 74% of BC)

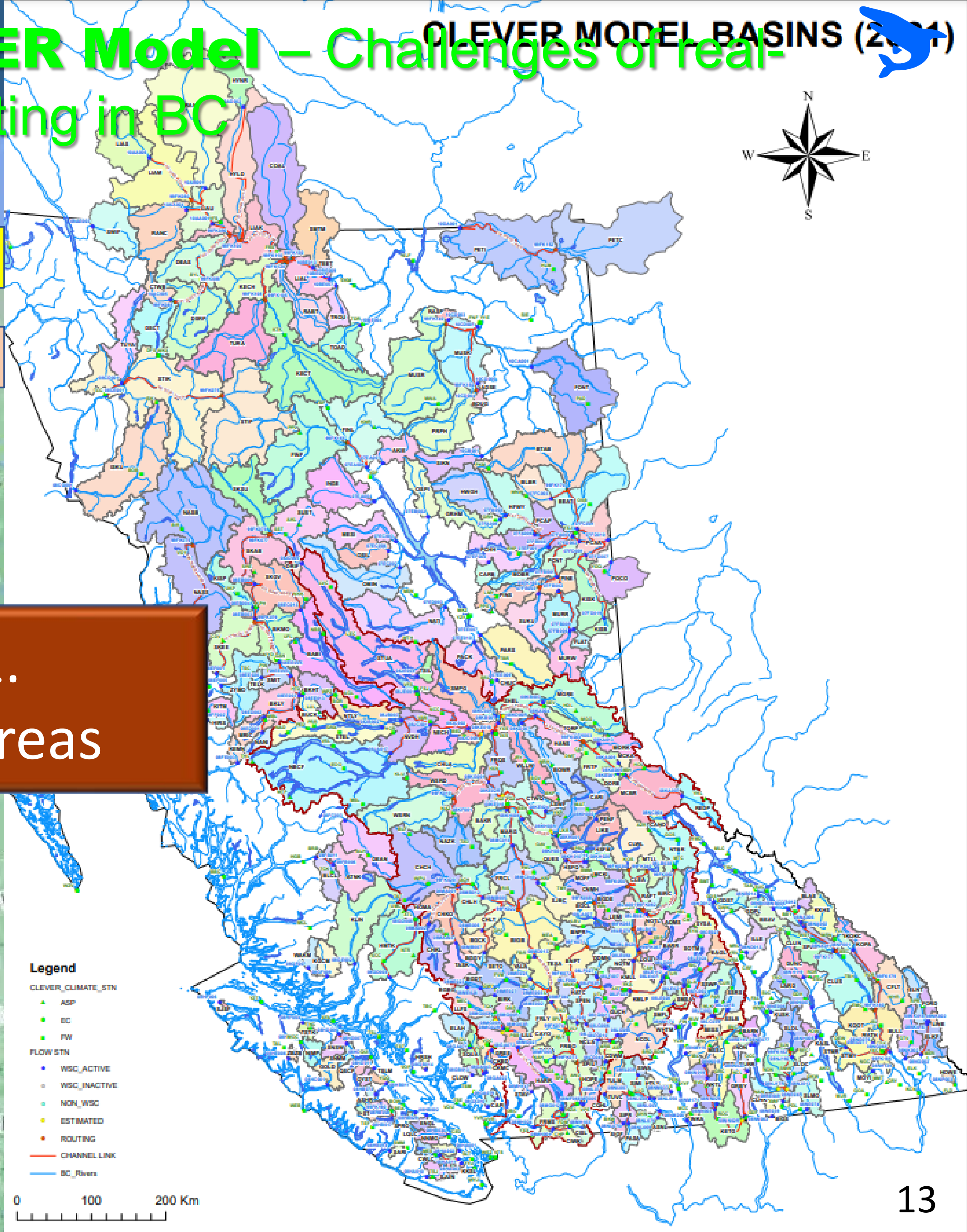
Model stations: 311

Area (km²):

British Columbia: 947,900
=91% of the following states:

| | |
|---|---|
| Washington: | 184,827 |
| Oregon: | 254,806 |
| Idaho: | 216,443 |
| Montana: | 380,800 |
| Total: | 1,036,876 |

## Challenge 1.
## Supper large areas



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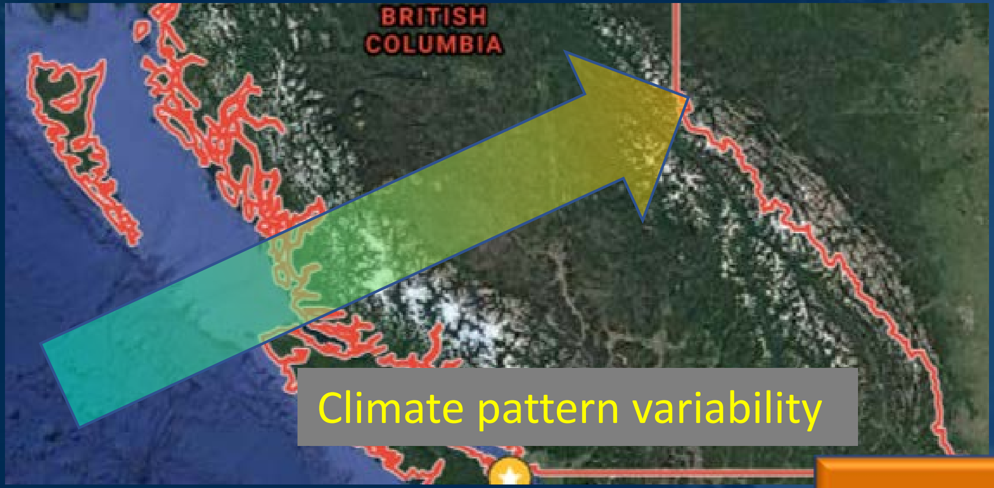
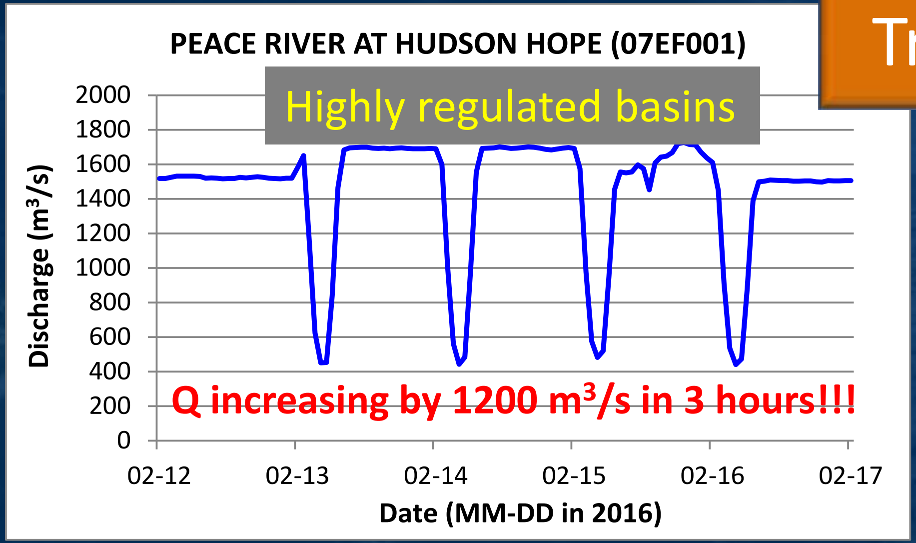
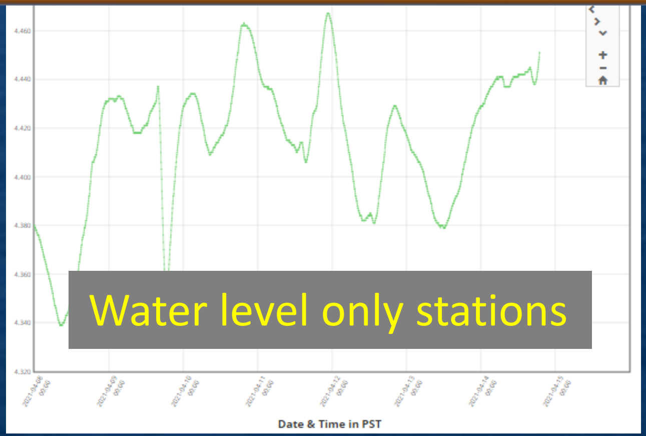
# 1. **Why the CLEVER Model** – Challenges of real-time flood forecasting in BC

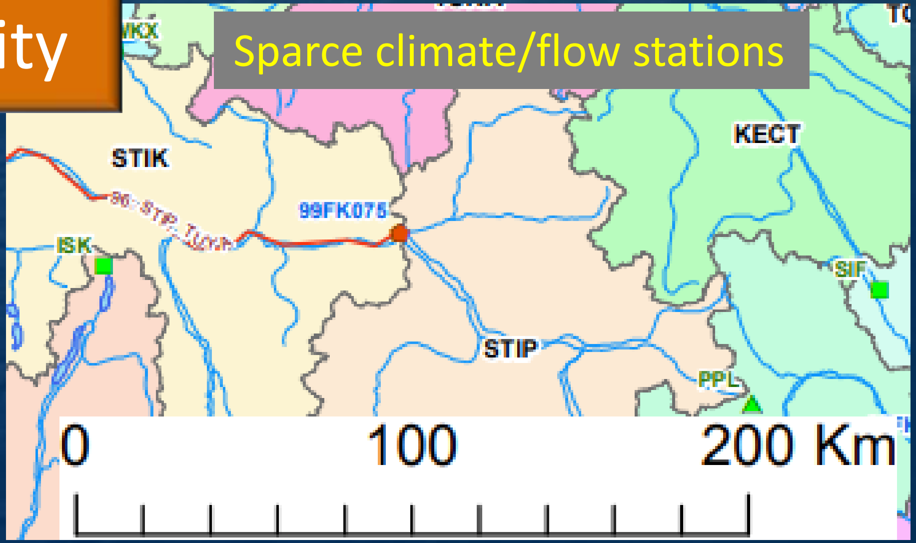





Challenge 2.
Tremendous heterogeneity



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# 1. **Why the CLEVER Model** – Challenges of real-time flood forecasting in BC

**Stantec Consulting Ltd, 2014. River Forecast Performance Measures Development Project Final Report, Alberta Environment and Sustainable Resource Development, Edmonton, AB**

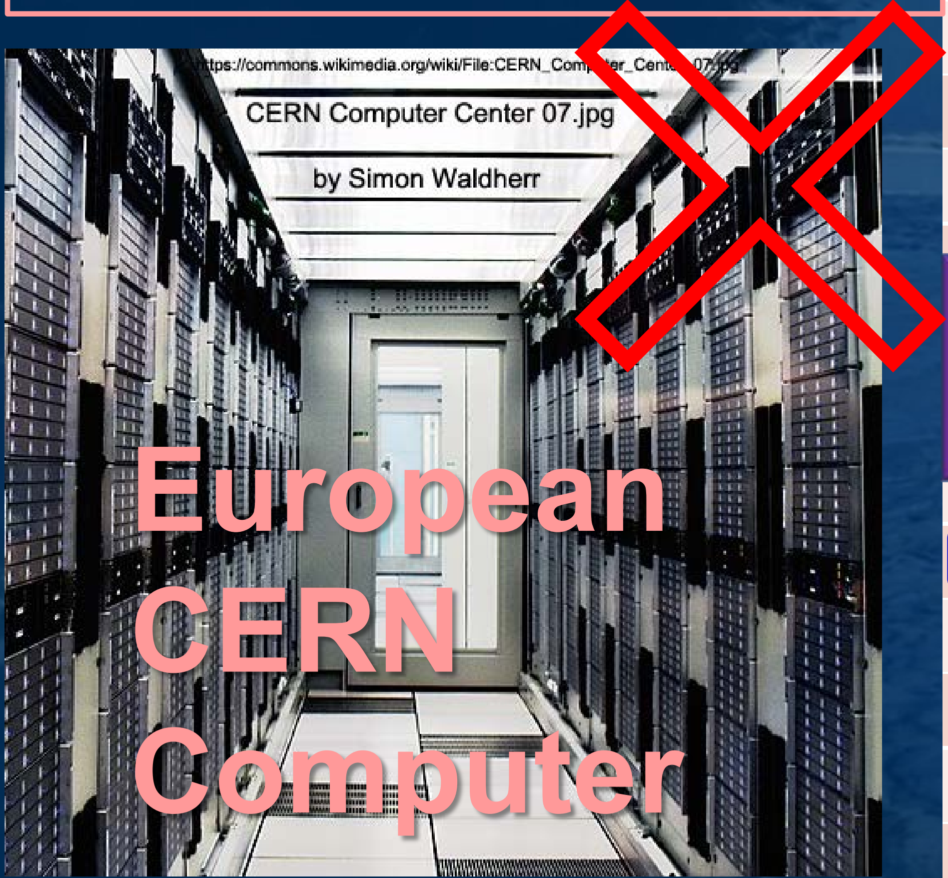
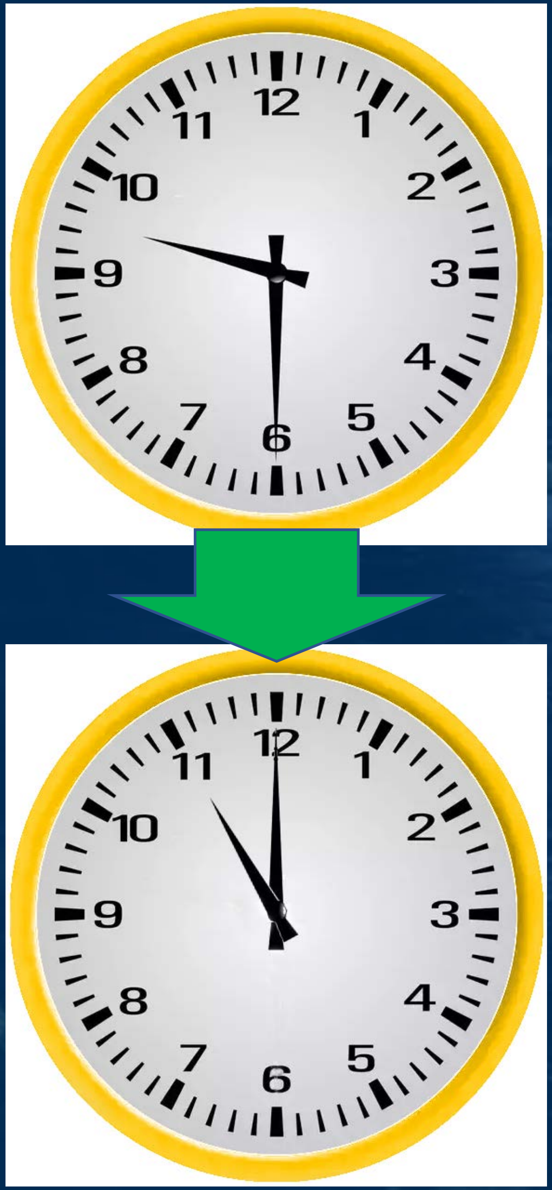



**Table 3-1: Flood Forecasting Centre Staffing**

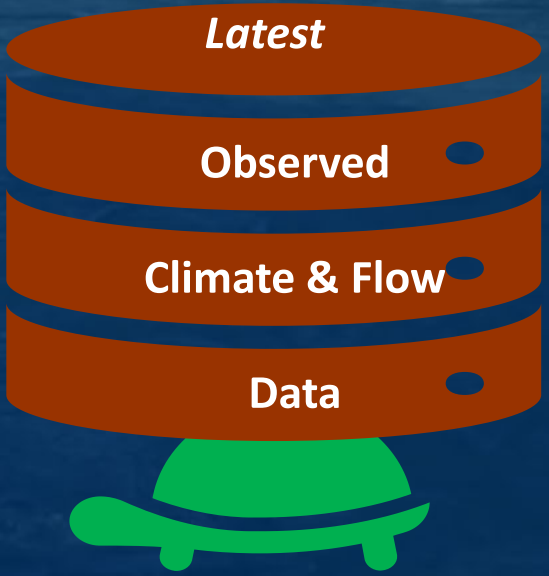
| FFC | No., of Staff | Forecast Area (km²) | Staff per service area ratio | Forecast Population | Staff per population ratio |
|---|---|---|---|---|---|
| CBRFC | 14 | 785,932 km² | ~ 1:56,000 | 12.7 M | ~ 1:1,000,000 |
| UD&FC | 23 | 7,770 km²** | ~ 1:340 | 2.3 M | ~ 1:100,000 |
| FCDMC | *** | 13,985km² | | 3.9 M | |
| ASWFN | | 295,280km² | | 6.5M | |
| [illegible] | [illegible] | [illegible] | 1:4,600 | 8.0 M | ~ 1:1,000,000 |
| [illegible] | [illegible] | [illegible] | 1:7,800 | 5.3 M | ~ 1:500,000 |
| [illegible] | [illegible] | [illegible] | 1:600 | 0.5 M | ~ 1:80,000 |
| GRCA | 41 | 7,000km² | ~1:170 | 985,000 | ~1:24,000 |
| BCRFC | 4.5 <=4 | 950,000 km² | ~ 1:200,000 | 4.5 M | ~ 1:900,000 |
| BRFC | 12 | 71,000 km² | ~ 1:6,000 | 12.0 M | ~ 1:1,000,000 |
| HFC | 12 | 650,000 km² | ~ 1:50,000 | 1.3 M | ~1:1,000,000 |
| ARFCWB* | 50 | Not available | | 22.7M | |
| HIC* | 25 | Not available | | 6M | |

**Challenge 3.**
**Very limited resources**

# 1. **Why the CLEVER Model** – Challenges of real-time flood forecasting in BC



Challenge 4.
Very limited time for modeling (about 90 minutes each day)



# 1. **Why the CLEVER Model** – Challenges of real-time flood forecasting in BC

Challenge 4.
Very limited time for modeling (about 90 minutes each day)

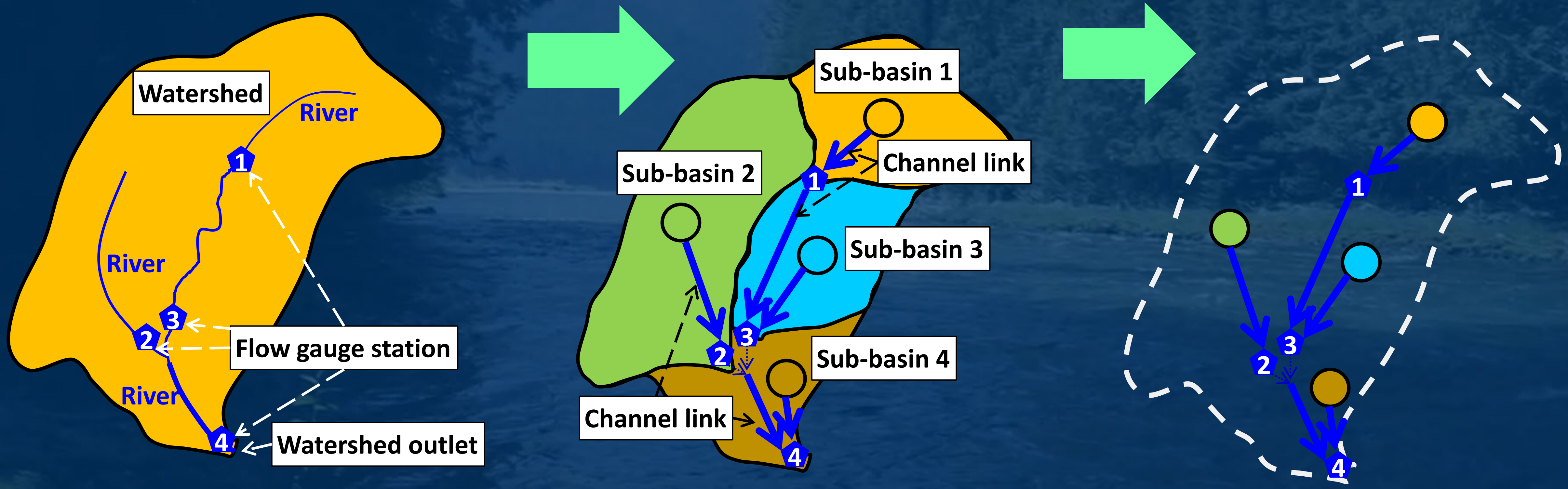
Challenge 3.
Very limited resources

Challenge 2.
Tremendous heterogeneity

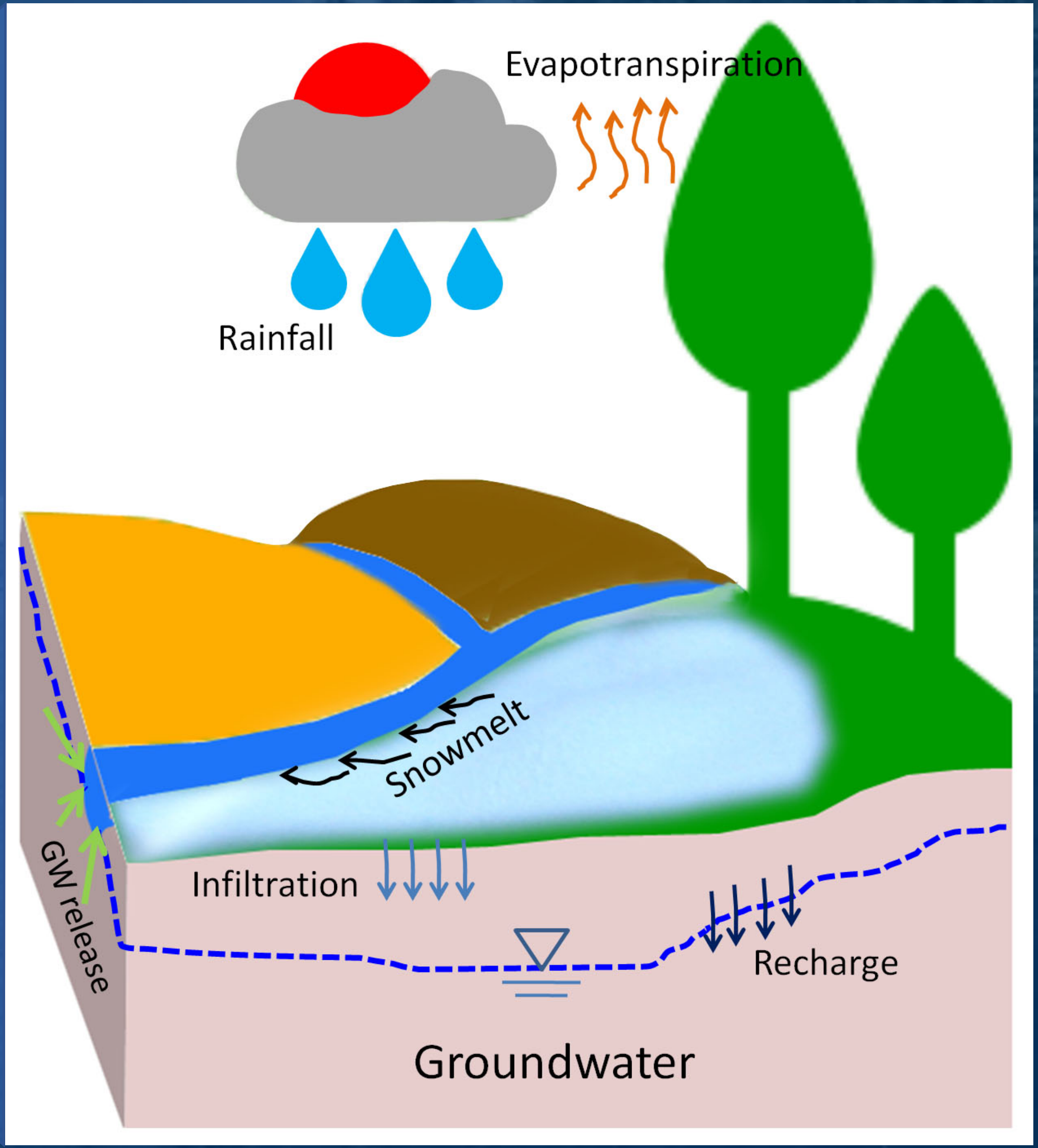
Challenge 1.
Supper large areas


**Channel Links Evolution Efficient Routing (CLEVER) Model**

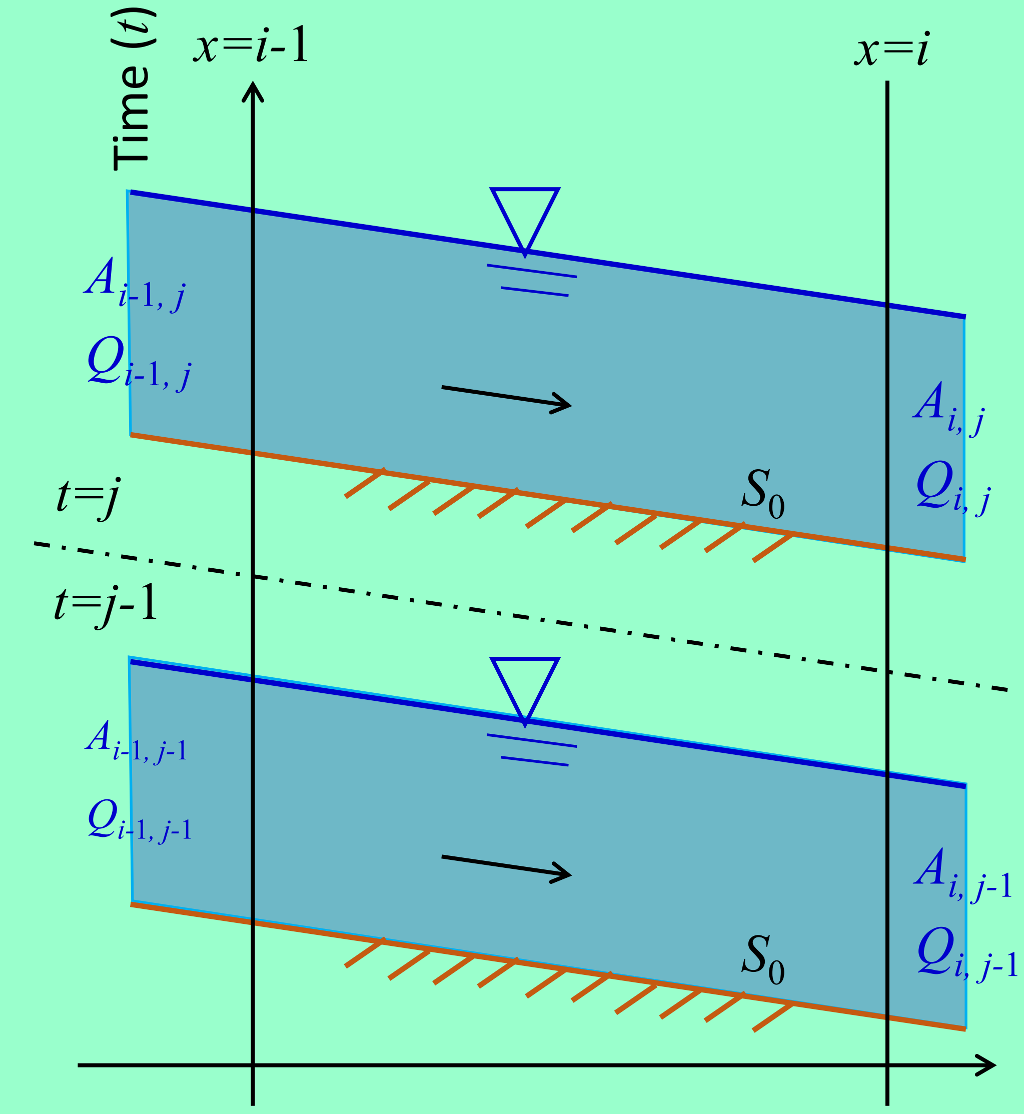
# 2. Model structure – watershed simplification



# 2. Model structure – Watershed routing



# 2. Model structure – Open channel routing




Improved kinematic wave scheme

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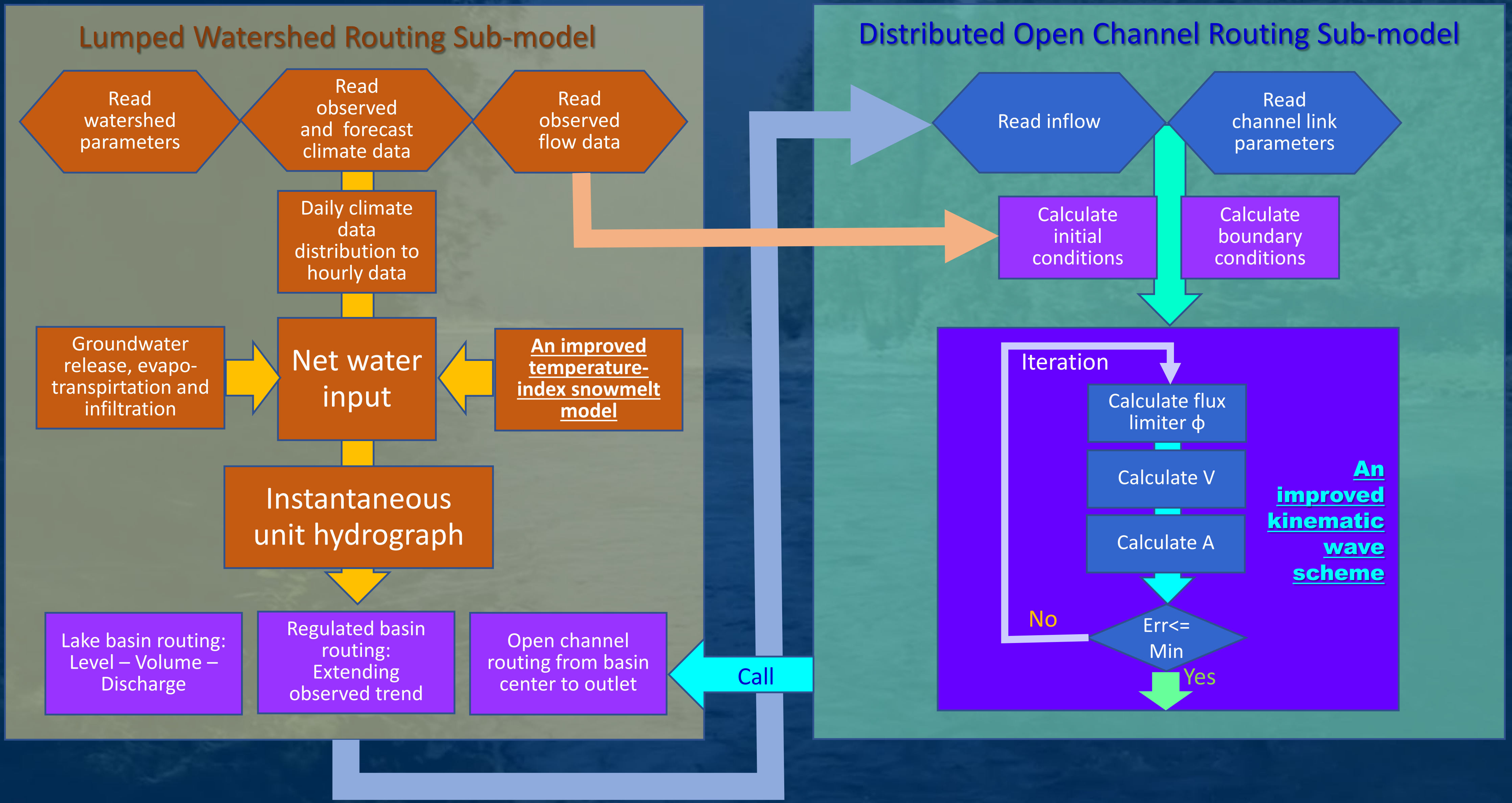
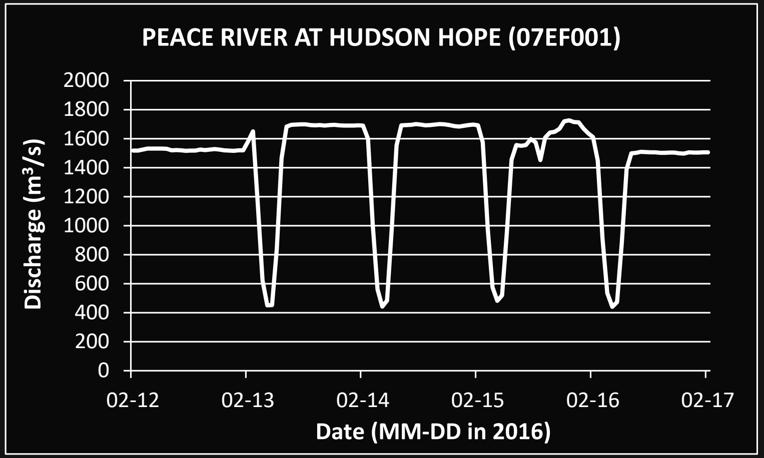
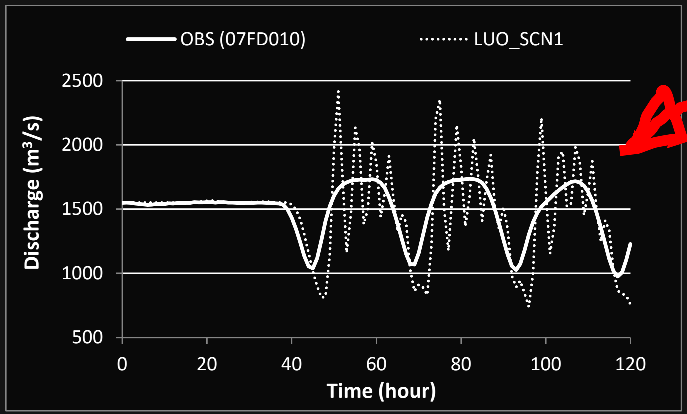
# 2. Model structure – Model flow chart



# 3. Science: Distributed open channel routing — An improved kinematic wave scheme




Highly regulated hydrograph




*Kinematic wave of Saint Venant Equation:*

$$\begin{cases} \frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \\ S_0 = \frac{n^2 Q^2}{A^2 R^{4/3}} \end{cases}$$

$$Q_{i,j} = V_{i,j} A_{i,j} \qquad V_{i,j} = \frac{1}{n}\sqrt{S_0} R_{i,j}^{2/3}$$

*Finite difference with the Preissmann scheme:*

$$A_{i,j} = \frac{\Delta t\left(Q_{i-1,j} + Q_{i-1,j-1} - Q_{i,j-1}\right) + \Delta x\left(A_{i,j-1} + A_{i-1,j-1} - A_{i-1,j}\right)}{\Delta t V_{i,j} + \Delta x}$$

*V unknow -> Iteration:*

$$\left(A_{i,j}\right)^{(k)} = \frac{\Delta t\left(Q_{i-1,j} + Q_{i-1,j-1} - Q_{i,j-1}\right) + \Delta x\left(A_{i,j-1} + A_{i-1,j-1} - A_{i-1,j}\right)}{\Delta t\left(V_{i,j}\right)^{(k-1)} + \Delta x}$$

$$r_{i,j} = \frac{Q_{i-1,j-1} - Q_{i-1,j-2}}{Q_{i-1,j} - Q_{i-1,j-1}} \qquad \varphi(r) = max[0, min(1, r)]$$

*Minmod Flux limiter*

$$\left(A_{i,j}\right)^{(k)} = \frac{\Delta t Q_{i-1,j} + \Delta x A_{i,j-1}}{\Delta t\left(V_{i,j}\right)^{(k-1)} + \Delta x} + \varphi(r_{ij}) \frac{\Delta t\left(Q_{i-1,j-1} - Q_{i,j-1}\right) + \Delta x\left(A_{i-1,j-1} - A_{i-1,j}\right)}{\Delta t\left(V_{i,j}\right)^{(k-1)} + \Delta x}$$

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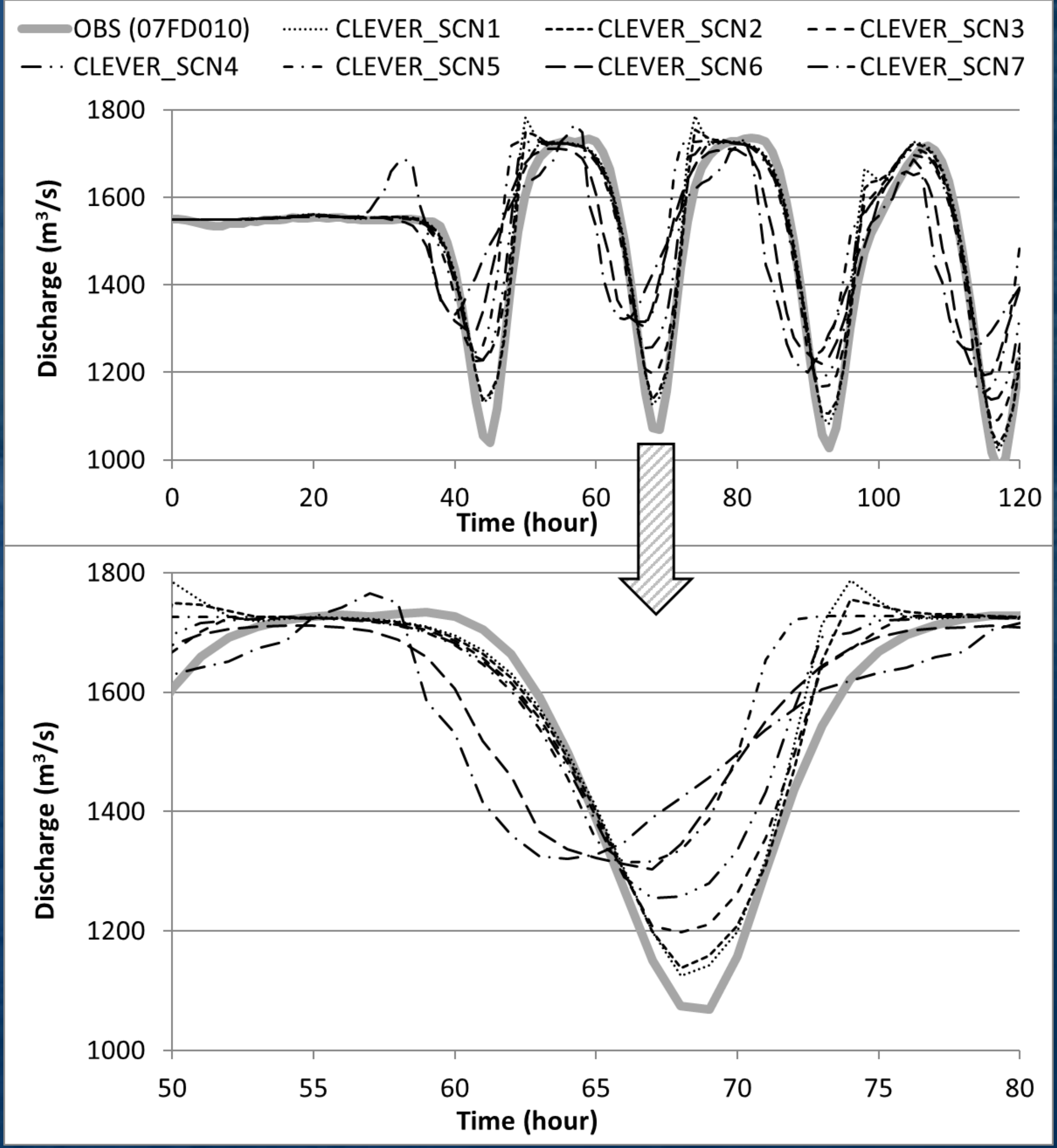
# 3. Science: Distributed open channel routing — An improved kinematic wave scheme

Luo, C. 2021. Comparing Five Kinematic Wave Schemes for Open-Channel Routing for Wide-Tooth-Comb-Wave Hydrographs. Journal of Hydrologic Engineering, ASCE, 26 (4).

**Table 2.** Basic scenarios

| River length (km) | $\Delta x$ (km) | $\Delta t$ (s) | $\Delta x/\Delta t$ (m/s) | River segments | Scenario |
|---|---|---|---|---|---|
| 150 | 1 | 3,600 | 0.278 | 150 | SCN1 |
| 150 | 2.5 | 3,600 | 0.694 | 60 | SCN2 |
| 150 | 5 | 3,600 | 1.389 | 30 | SCN3 |
| 150 | 7.5 | 3,600 | 2.083 | 20 | SCN4 |
| 150 | 10 | 3,600 | 2.778 | 15 | SCN5 |
| 150 | 25 | 3,600 | 6.944 | 6 | SCN6 |
| 150 | 50 | 3,600 | 13.889 | 3 | SCN7 |

Note: $\Delta t = 1$ h $= 3{,}600$ s.



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# **4. Science:** Lumped watershed routing – An improved temperature-index snowmelt model



Water balance equation:

$$W = R + M + G - E - I$$

Temperature-index method:

$$\boldsymbol{M = M_f(T_i - T_b)}$$

$M$: snowmelt

$M_f$: melt factor

$T_i$: air temperature

$T_b$: base temperature snow starts to melt

$x=y$

Simple

Time Efficiency

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# **4. Science:** Lumped watershed routing – An improved temperature-index snowmelt model

Large portion of radiation absorbed by vegetation for photosynthesis

Hourly time step shorter than time needs for snow to melt as estimated

**Overestimate slope of rise (steeper)**

*T* usually lags and attenuate in daytime

Energy for melt is nonlinear to *T*

**Underestimate slope of rise (flatter)**

**Improved**

Temperature-index on watershed-scale using hourly time step:

$$M = c_a c_d M_f (T_i - T_b)^{\beta}$$

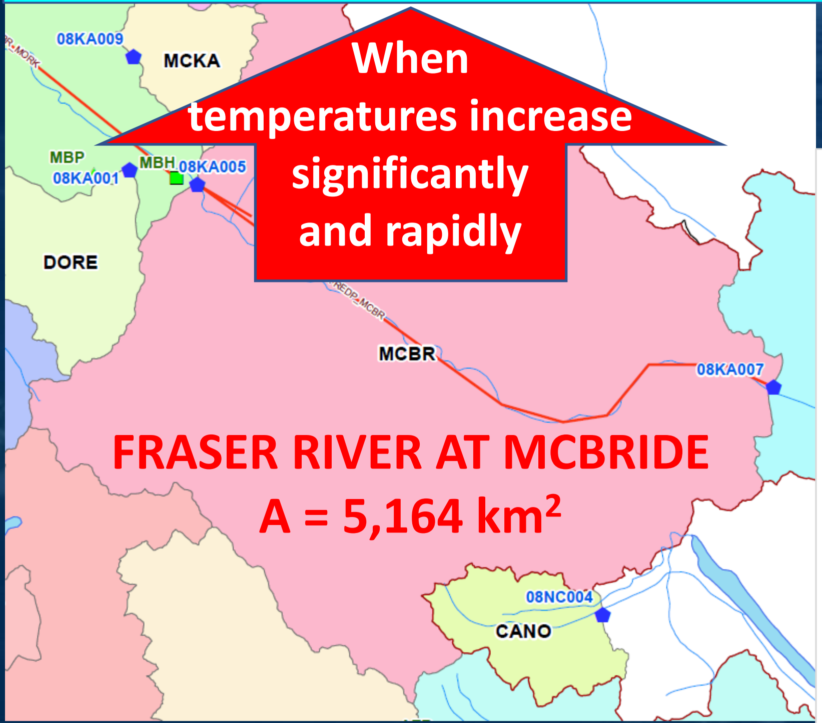
$c_a$: snow covering correction factor during the snowpack receding period (<=1):

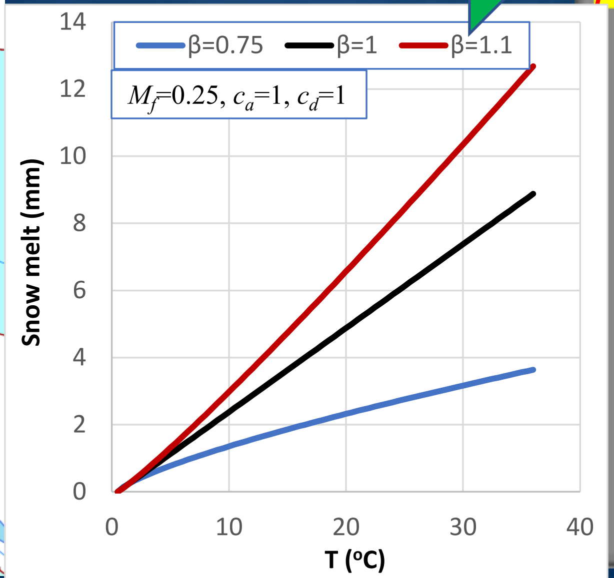
$$c_a = \left(\frac{SWE_i}{SWE_{max}}\right)^{\alpha}$$

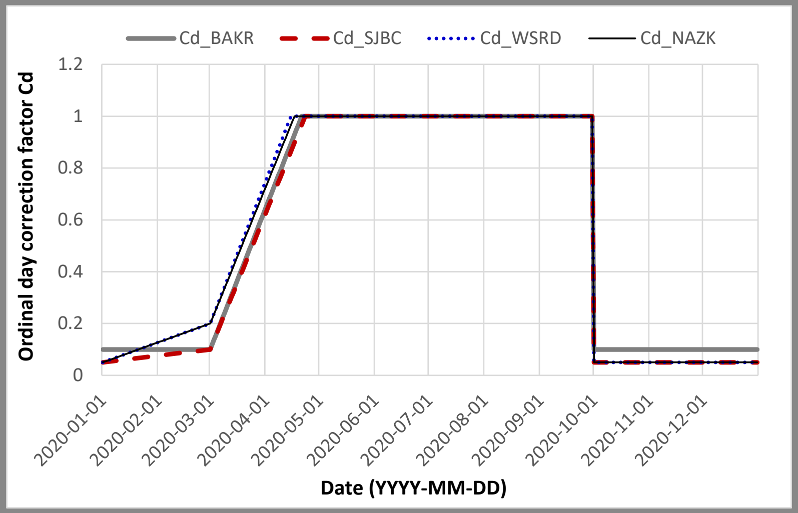
$c_d$: Ordinal day correction factor (<=1)

$\alpha$: snowpack covering area receding power

$\beta$: temperature power, which could be >,=,<1



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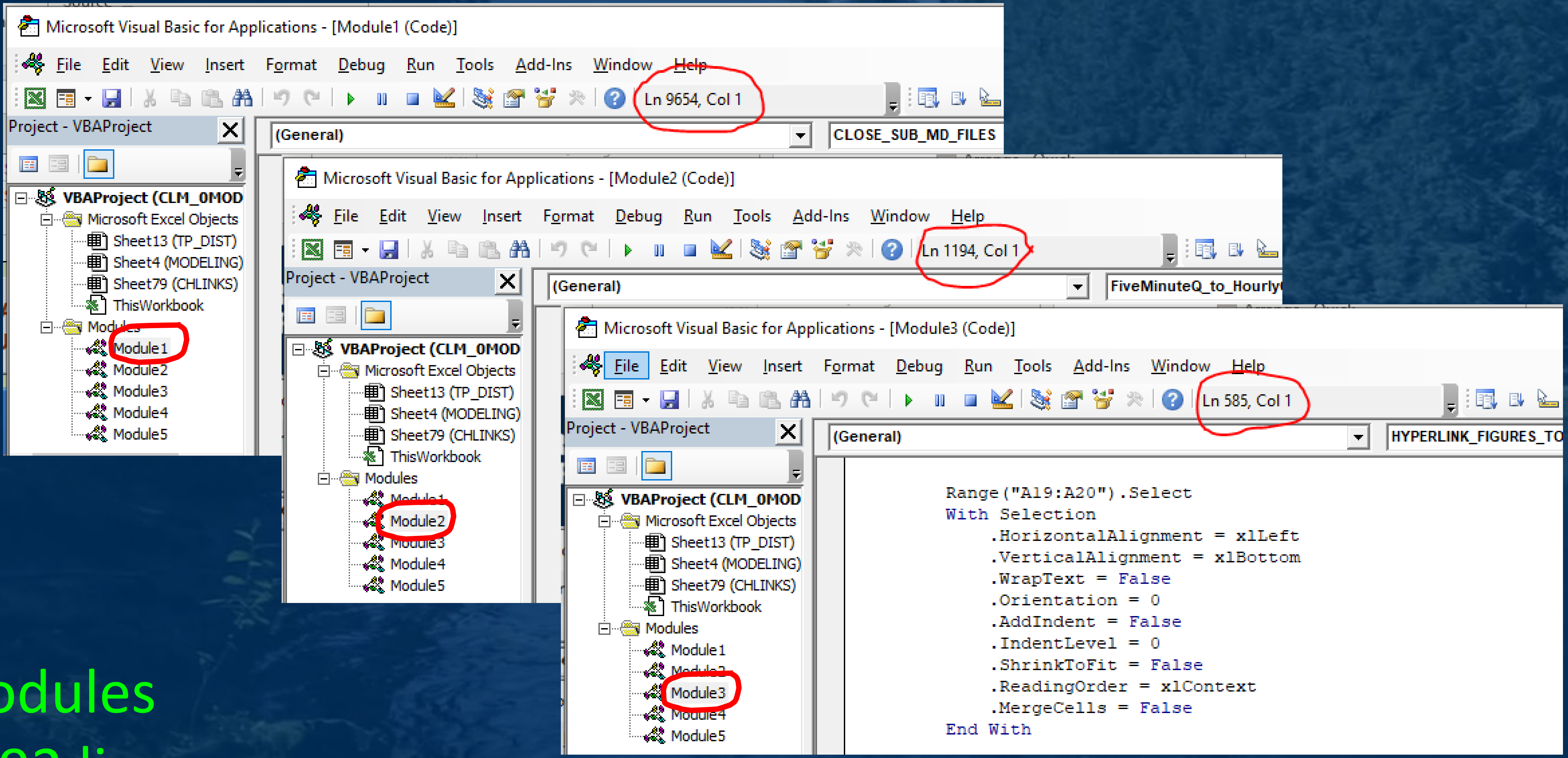
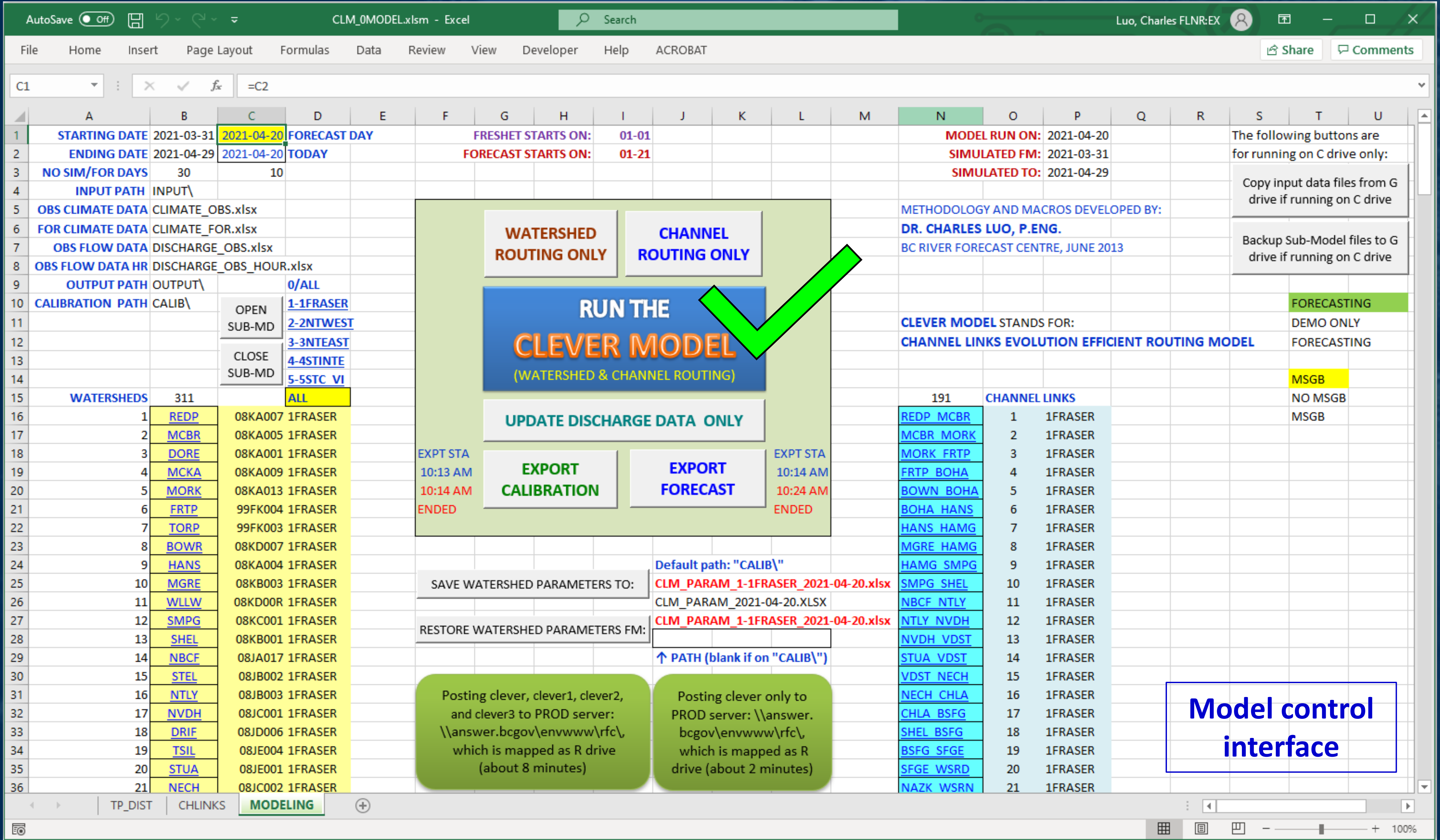
# 5. Codes and user interface




5 modules

12,492 lines

# 5. Codes and user interfaces




Model control interface

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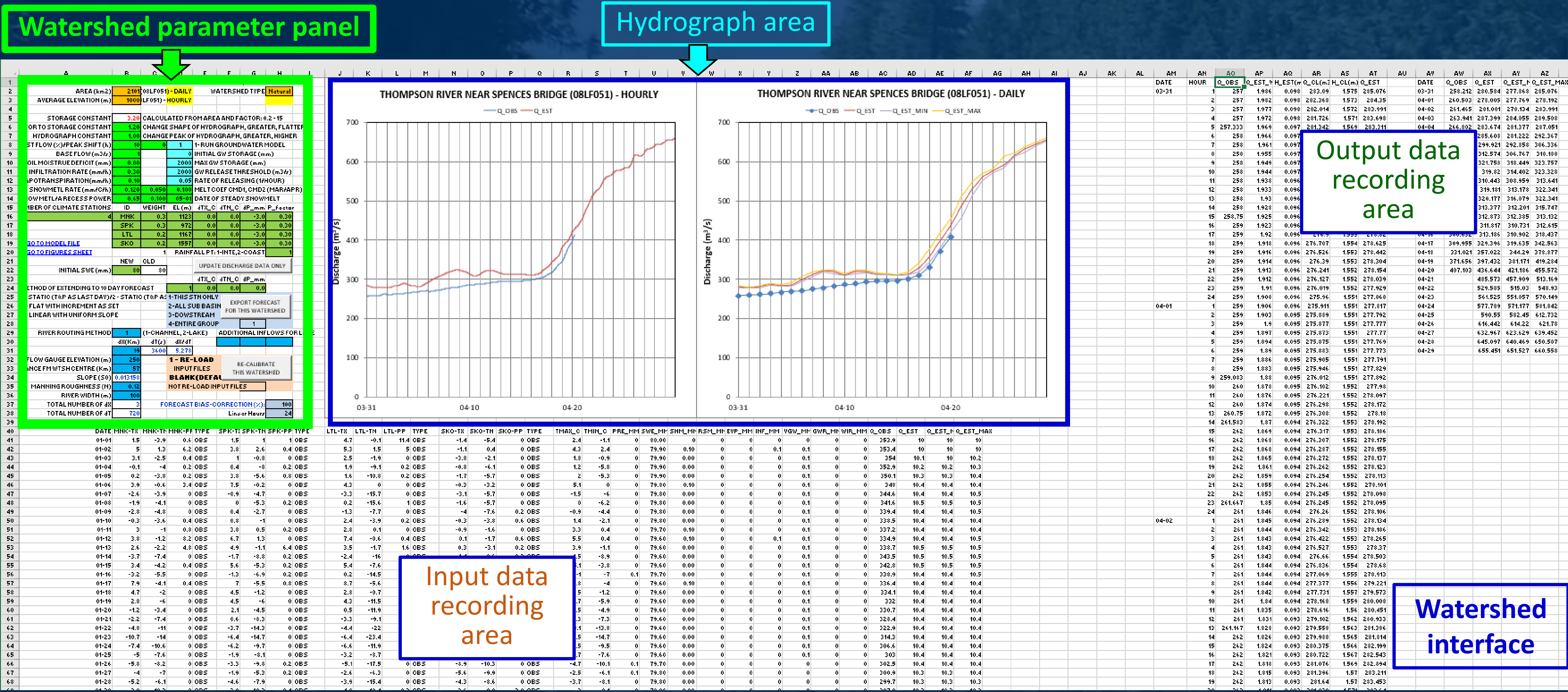
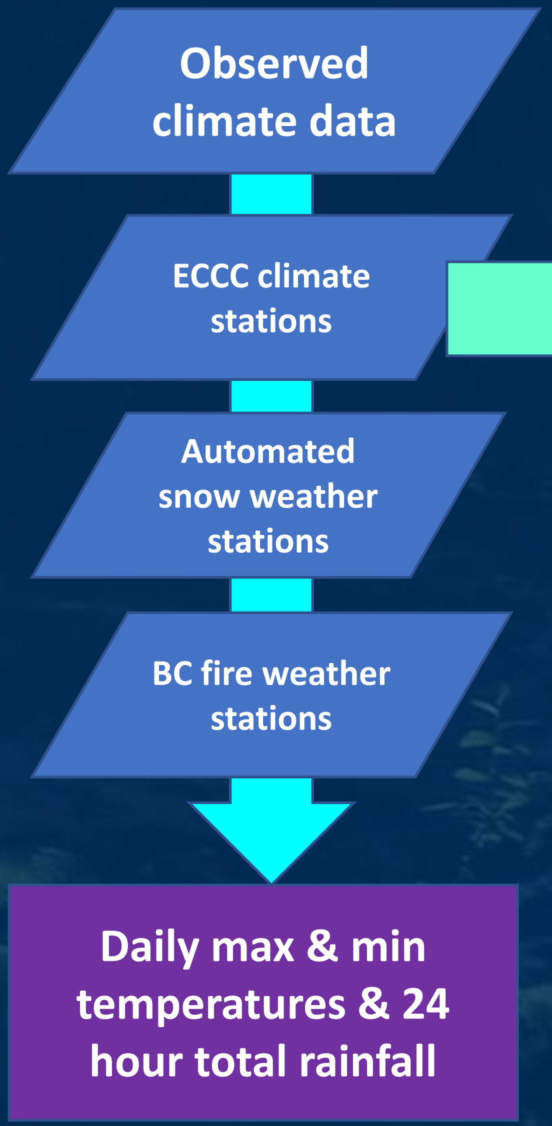
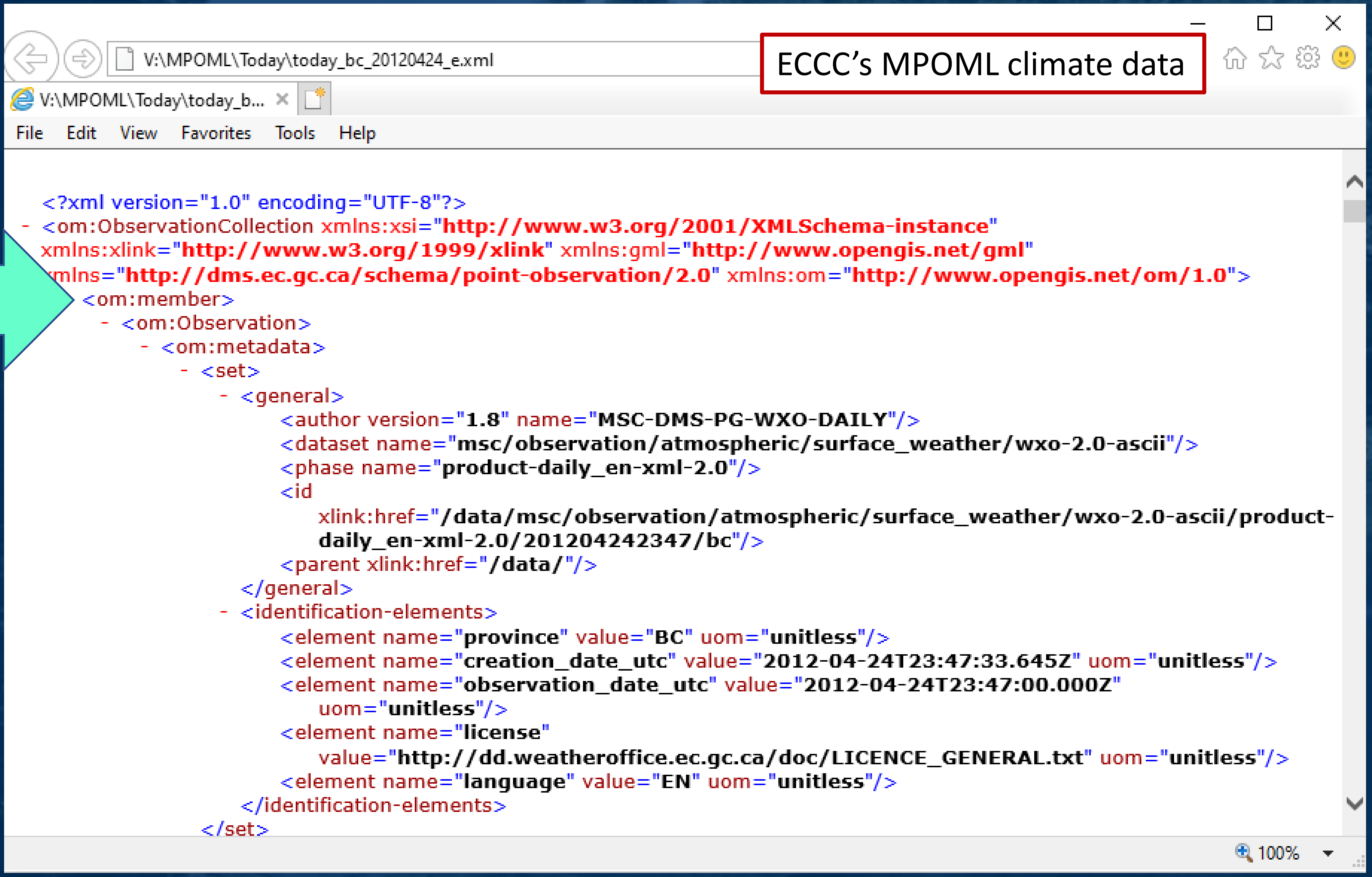
# 5. Codes and user interfaces



# 6. Input data and data assimilation



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# 6. Input data and data assimilation

**Forecast climate data**

Canadian Meteorological Centre's (CMC) Numerical Weather Prediction (NWP) - GRIB2 format

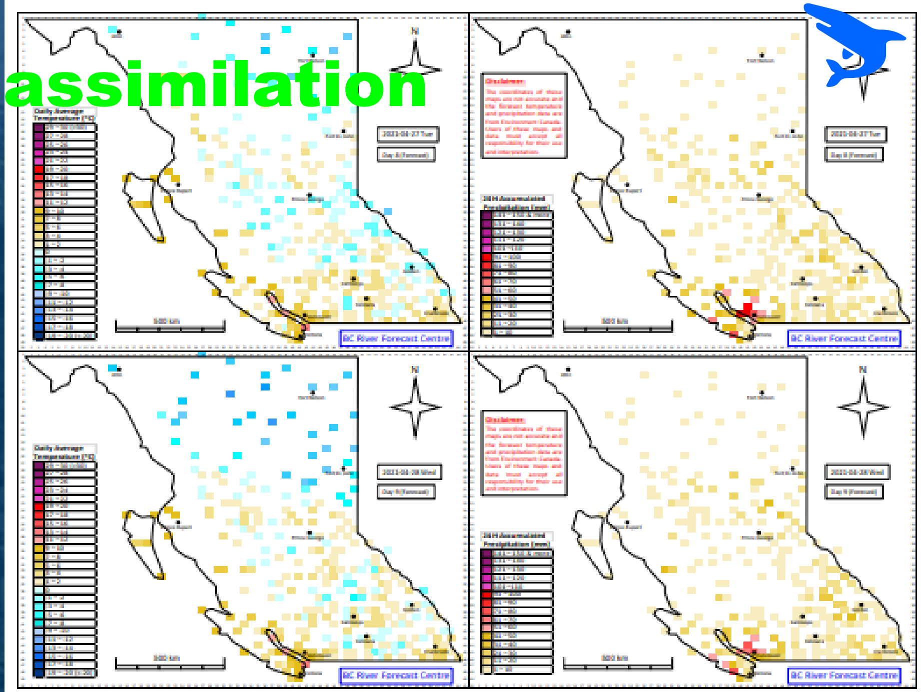
- Regional Deterministic Prediction System - RDPS (dx=10 km, dt=3h, Time=0 to 62h)

- Global Deterministic Prediction System - GDPS (dx= 25 km, dt =3h, Time used= 63 to 240h)

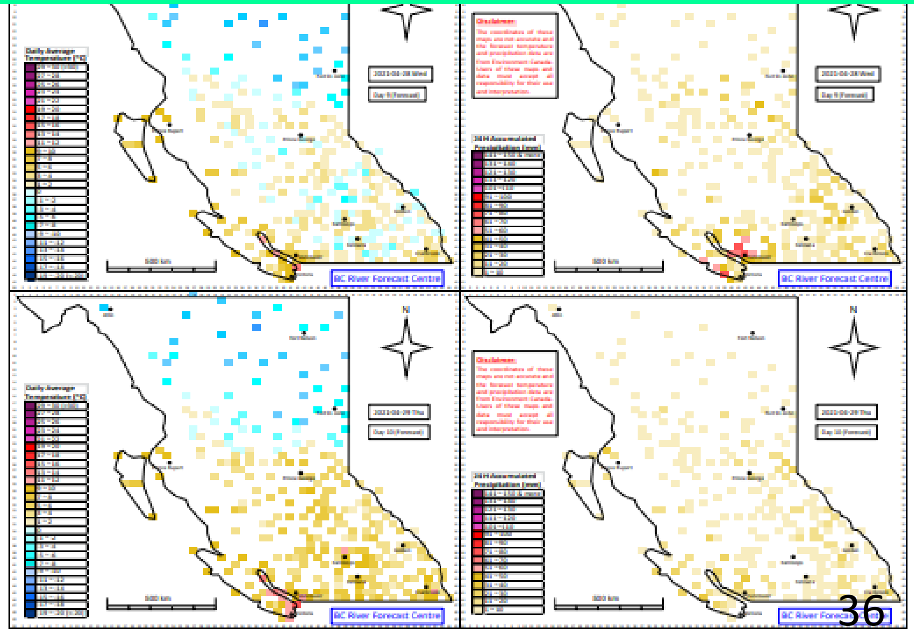
161 files to download (about 20 minutes)

**Downscale to**

Locations of 368 climate stations (about 20 minutes)



**Map of CMC's10 forecasts of daily average T and daily P**
http://bcrfc.env.gov.bc.ca/freshet/FORECAST_CMC_MAP.pdf



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# 6. Input data and data assimilation

**Observed Hydrometric data**

Water Survey of Canadian DataMart hydrometric data

**Hourly + Daily**

| | A | B | C | PB | PC | PD |
|---|---|---|---|---|---|---|
| 1 | | | | 08PA012 | 08MB012 | 10AA001 |
| 25345 | | | 55 | 8.28 | 38.6 | |
| 25346 | 03-30 | 0 | 0 | 8.39 | 38.7 | 65 |
| 25347 | | | 5 | 8.24 | 39.1 | |
| 25348 | | | 10 | 8.13 | 39.1 | |
| 25349 | | | 15 | 8.43 | 38.3 | 65 |
| 25350 | | | 20 | 8.28 | 39 | |
| 25351 | | | 25 | 8.35 | 38.8 | |
| 25352 | | | 30 | 8.28 | 39.2 | 65 |
| 25353 | | | 35 | 8.32 | 38.7 | |
| 25354 | | | 40 | 8.24 | 39 | |
| 25355 | | | 45 | 8.28 | 38.6 | 65 |
| 25356 | | | 50 | 8.35 | 38.2 | |
| 25357 | | | 55 | 8.43 | 38.3 | |
| 25358 | | 1 | 0 | 8.28 | 38.6 | 65 |
| 25359 | | | 5 | 8.28 | 37.9 | |
| 25360 | | | 10 | 8.2 | 37.6 | |
| 25361 | | | 15 | 8.2 | 37.2 | 65 |
| 25362 | | | 20 | 8.2 | 37.6 | |
| 25363 | | | 25 | 8.24 | 37 | |
| 25364 | | | 30 | 8.24 | 38.2 | 64.9 |
| 25365 | | | 35 | 8.24 | 38.2 | |
| 25366 | | | 40 | 8.2 | 38.3 | |
| 25367 | | | 45 | 8.17 | 38.4 | 64.9 |
| 25368 | | | 50 | 8.17 | 38.4 | |
| 25369 | | | 55 | 8.24 | 37.9 | |
| 25370 | | 2 | 0 | 8.2 | 38.4 | 64.9 |
| 25371 | | | 5 | 8.2 | 38.2 | |
| 25372 | | | 10 | 8.02 | 38 | |
| 25373 | | | [illegible] | [illegible] | [illegible] | 64.9 |
| 25374 | | | [illegible] | [illegible] | [illegible] | |
| 25375 | | | [illegible] | [illegible] | [illegible] | |
| 25376 | | | [illegible] | [illegible] | [illegible] | 64.9 |
| 25377 | | | 35 | 8.13 | 38.4 | |
| 25378 | | | 40 | 8.2 | 38.4 | |
| 25379 | | | 45 | 8.17 | 38.7 | 64.9 |

Different time step

| | A | B | C | IK | IL | IM | IN | IO | IP |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | 08NA002 | 08NA006 | 08NA011 | 08NB005 | 08NB017 | 08NB019 |
| 25345 | | | 55 | 31.4 | 7.67 | 5.4 | 44.2 | | |
| 25346 | 03-30 | 0 | 0 | 31.4 | | 5.4 | 37.7 | | |
| 25347 | | | 5 | 31.4 | | 5.37 | 44.2 | | |
| 25348 | | | 10 | 31.4 | 7.7 | 5.37 | 44.2 | | |
| 25349 | | | 15 | 31.4 | | 5.37 | 37.7 | | |
| 25350 | | | 20 | 31.4 | | 5.37 | 44.2 | | |
| 25351 | | | 25 | 31.4 | 7.62 | 5.37 | 44.2 | | |
| 25352 | | | 30 | 31.4 | 7.67 | 5.35 | 37.7 | | |
| 25353 | | | 35 | 31.4 | | 5.35 | 44.1 | | |
| 25354 | | | 40 | 31.4 | | [illegible] | [illegible] | | |
| 25355 | | | 45 | 31.3 | | [illegible] | [illegible] | | |
| 25356 | | | 50 | 31.4 | 7.79 | [illegible] | [illegible] | | |
| 25357 | | | 55 | 31.3 | 7.64 | [illegible] | [illegible] | | |
| 25358 | | 1 | 0 | 31.3 | 7.67 | [illegible] | [illegible] | | |
| 25359 | | | 5 | 31.3 | | 5.32 | 44 | | |
| 25360 | | | 10 | 31.3 | 7.73 | 5.32 | 44 | | |
| 25361 | | | 15 | 31.3 | | 5.32 | 37.7 | | |
| 25362 | | | 20 | 31.3 | | 5.32 | 43.9 | | |
| 25363 | [illegible] | [illegible] | [illegible] | [illegible] | 7.76 | 5.32 | 43.9 | | |
| 25364 | [illegible] | [illegible] | [illegible] | [illegible] | 7.59 | 5.32 | 37.7 | | |
| 25365 | [illegible] | [illegible] | [illegible] | [illegible] | 7.73 | 5.32 | 43.9 | | |
| 25366 | [illegible] | [illegible] | [illegible] | [illegible] | | 5.29 | 43.9 | | |
| 25367 | | | 45 | 31.3 | | 5.29 | 37.7 | | |
| 25368 | | | 50 | 31.3 | | 5.29 | 43.9 | | |
| 25369 | | | 55 | 31.3 | 7.62 | 5.29 | 43.9 | | |
| 25370 | | 2 | 0 | 31.3 | 7.62 | 5.29 | 37.7 | | |
| 25371 | | | 5 | 31.3 | 7.73 | 5.29 | 43.8 | | |
| 25372 | | | 10 | 31.3 | | 5.29 | 43.8 | | |
| 25373 | | | 15 | 31.3 | | 5.29 | 37.7 | | |
| 25374 | | | 20 | 31.3 | 7.73 | 5.29 | 43.8 | | |
| 25375 | | | 25 | 31.3 | | 5.29 | 43.8 | | |
| 25376 | | | 30 | 31.3 | 7.56 | 5.29 | 37.7 | | |
| 25377 | | | 35 | 31.2 | 7.47 | 5.29 | 43.8 | | |
| 25378 | | | 40 | 31.3 | | 5.29 | 43.8 | | |
| 25379 | | | 45 | 31.3 | | 5.29 | 37.7 | | |

Irregularly missing

Completely missing

Real-Time Hydrometric Data Graph for MCGREGOR RIVER AT LOWER CANYON (08KB003) [BC]

Station Notice

The regular flow measurement program at this hydrometric gauge is compromised because the cableway is currently out of service. Please email ec.shnhydrologiquebc-nhshydrologicalbc.ec@canada.ca with any questions or concerns.

All times are specified in Local S... ing Time where and when it is observed.

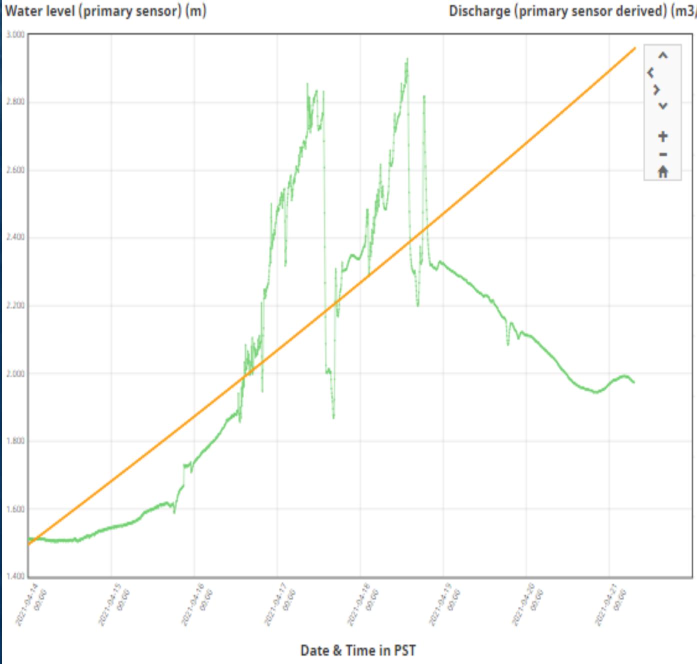
Obviously wrong data

Graph | Tabl

Station: 08KB003 | Data Type: Real-Time | Download? | Apply

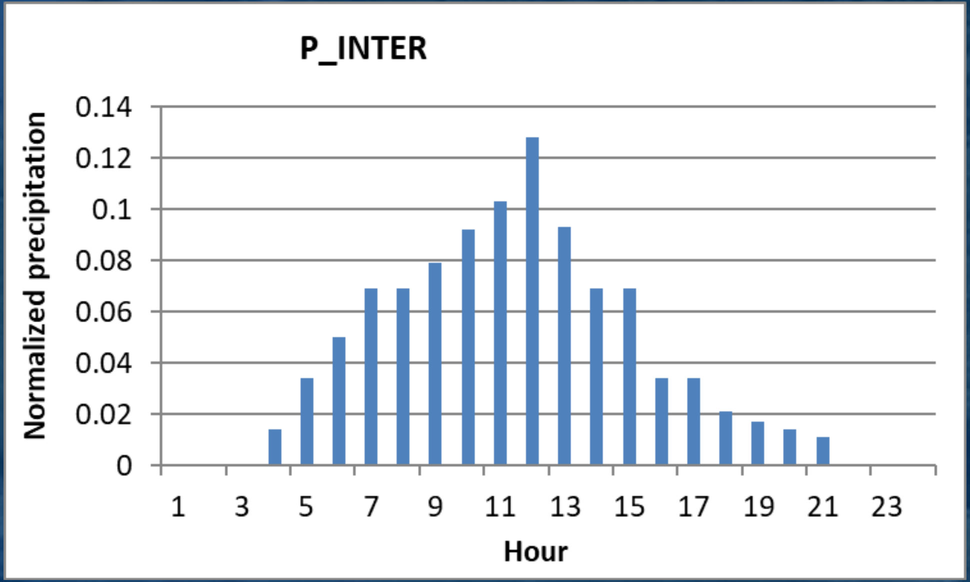
Legend

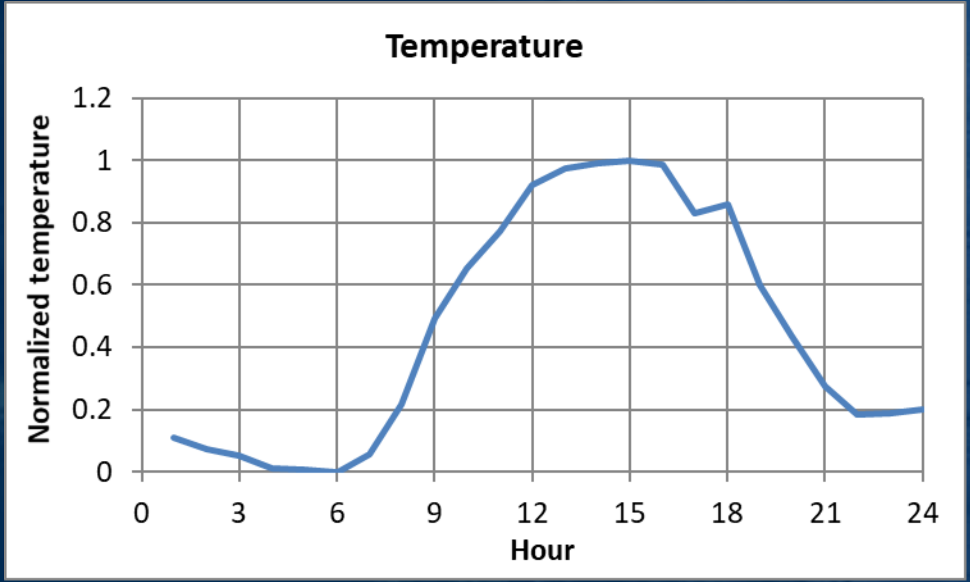
Water level (primary sensor) - Provisional | Discharge (primary sensor derived) - Provisional

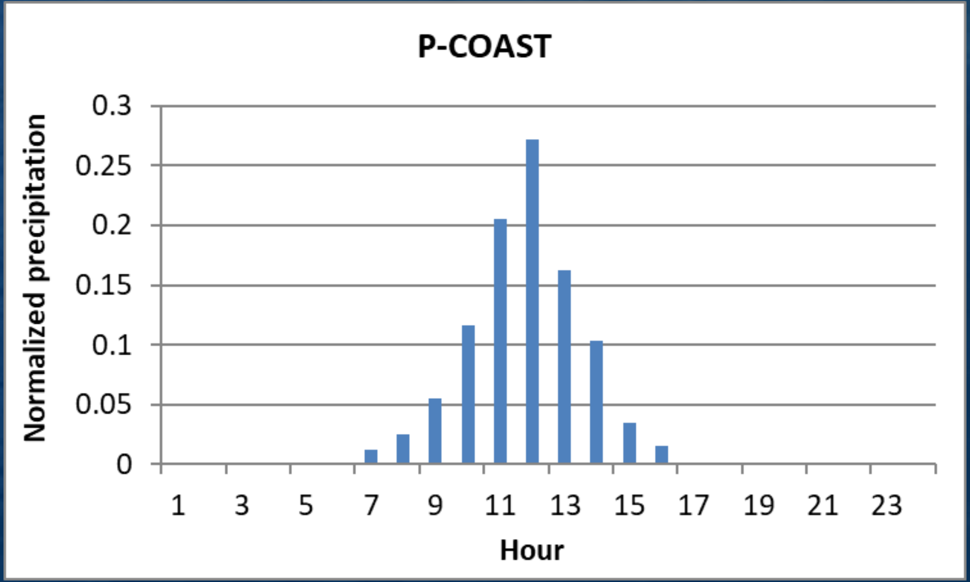


# 6. Input data and data assimilation

In the model:
Dily climate data are distributed to hourly data

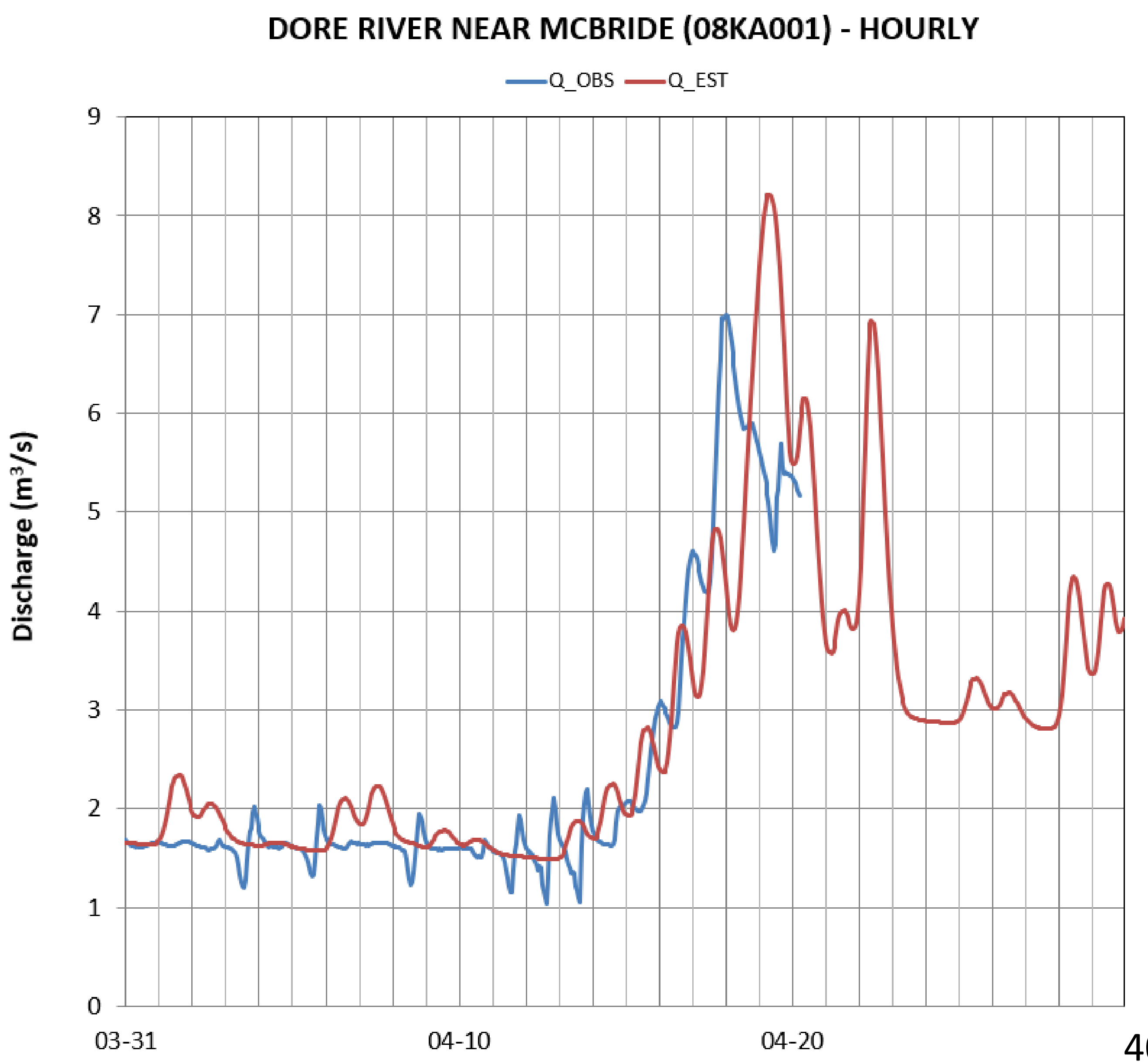


# 7. Model calibration – flexibility to adapt to climate changes

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | WATERSHED | DORE RIVER NEAR MCBRIDE (08KA001) | | | | | | DORE |
| 2 | AREA (km2) | 407 | (08KA001) - DAILY | | | WATERSHED TYPE | | Natural |
| 3 | AVERAGE ELEVATION (m) | 1600 | )8KA001) - HOURLY | | | | | |
| 4 | | | | | | | | |
| 5 | STORAGE CONSTANT | 2.00 | CALCULATED FROM AREA AND FACTOR: 0.2 - 15 | | | | | |
| 6 | FACTOR TO STORAGE CONSTANT | 1.20 | CHANGE SHAPE OF HYDROGRAPH, GREATER, FLATTER | | | | | |
| 7 | HYDROGRAPH CONSTANT | 1.00 | CHANGE PEAK OF HYDROGRAPH, GREATER, HIGHER | | | | | |
| 8 | FAST FLOW (%)/PEAK SHIFT (H) | 1 | 0 | 1 | 1- RUN GROUNDWATER MODEL | | | |
| 9 | BASE FLOW (m3/s) | 0.5 | | 0 | INITIAL GW STORAGE (mm) | | | |
| 10 | SOIL MOISTRUE DEFICIT (mm) | 0.00 | | 1000 | MAX GW STORAGE (mm) | | | |
| 11 | INFILTRATION RATE (mm/h) | 0.40 | | 200 | GW RELEASE THRESHOLD (m3/s) | | | |
| 12 | EVAPOTRANSPIRATION(mm/H) | 0.05 | | 0.15 | RATE OF RELEASING (1/HOUR) | | | |
| 13 | SNOWMETL RATE (mm/C/H) | 0.360 | 0.050 | 0.300 | MELT COEF CMD1, CMD2 (MAR/APR) | | | |
| 14 | SNOW METL/A RECESS POWER | 0.75 | 0.200 | 05-21 | DATE OF STEADY SNOWMELT | | | |
| 15 | NUMBER OF CLIMATE STATIONS | ID | WEIGHT | EL (m) | dTX_C | dTN_C | dP_mm | P_factor |
| 16 | 2 | MBP | 0.6 | 1611 | 0.0 | 0.0 | -4.0 | 0.80 |
| 17 | | MBH | 0.4 | 716 | 0.0 | 0.0 | -5.0 | 0.70 |
| 18 | | | | | | | | |
| 19 | <-GO TO MODEL FILE | | | | | | | |
| 20 | <-GO TO FIGURES SHEET | | 1 | RAINFALL PT: 1-INTE,2-COAST | | | | 1 |
| 21 | | NEW | OLD | | | | | |
| 22 | INITIAL SWE (mm) | 1200 | 1200 | | UPDATE DISCHARGE DATA ONLY | | | |
| 23 | | | | | dTX_C | dTN_C | dP_mm | |
| 24 | METHOD OF EXTENDING TO 10 DAY FORECAST | | | 1 | 0.0 | 0.0 | 0.0 | |
| 25 | 1 - STATIC (T&P AS LAST DAY)/2 - STATIC (T&P AS SET) | | | 1-THIS STN ONLY | EXPORT FORECAST FOR THIS WATERSHED | | | |
| 26 | 3 - FLAT WITH INCREMENT AS SET | | | 2-ALL SUB BASINS | | | | |
| 27 | 4 - LINEAR WITH UNIFORM SLOPE | | | 3-DOWSTREAM | | | | |
| 28 | | | | 4-ENTIRE GROUP | | | 1 | |
| 29 | RIVER ROUTING METHOD | 1 | (1-CHANNEL, 2-LAKE) | | | ADDITIONAL INFLOWS FOR LAKE | | |
| 30 | | dX(Km) | dT(s) | dX/dT | | | | |
| 31 | | 8 | 3600 | 2.222 | | | | |
| 32 | FLOW GAUGE ELEVATION (m) | 750 | | 1 - RE-LOAD | RE-CALIBRATE THIS WATERSHED | | | |
| 33 | DISTANCE FM WTSH CENTRE (Km) | 16 | | INPUT FILES | | | | |
| 34 | SLOPE (S0) | 0.052125 | | BLANK(DEFAULT) - | | | | |
| 35 | MANNING ROUGHNESS (N) | 0.12 | | NOT RE-LOAD INPUT FILES | | | | |
| 36 | RIVER WIDTH (m) | 40 | | | | | | |
| 37 | TOTAL NUMBER OF dX | 2 | | FORECAST BIAS-CORRECTION (%): | | | | 0 |
| 38 | TOTAL NUMBER OF dT | 720 | | | | | Linear Hours | 12 |



# 7. Model calibration – flexibility to adapt to climate changes

| DATE | HOUR | Q_OBS | Q_EST_W | H_EST(m) |
|---|---|---|---|---|
| 01-01 | 1 | 3.76 | 2 | 0.148 |
| | 2 | 3.76 | 2 | 0.148 |
| | 3 | 3.76 | 2 | 0.148 |
| | 4 | 3.76 | 2 | 0.148 |
| | 5 | 3.76 | 2 | 0.148 |
| | 6 | 3.76 | 2 | 0.148 |
| | 7 | 3.76 | 2 | 0.148 |
| | 8 | 3.76 | 2 | 0.148 |

Observed & estimated discharges/water levels

WATERSHED ROUTING ONLY

CHANNEL ROUTING ONLY

RUN THE CLEVER MODEL (WATERSHED & CHANNEL ROUTING)

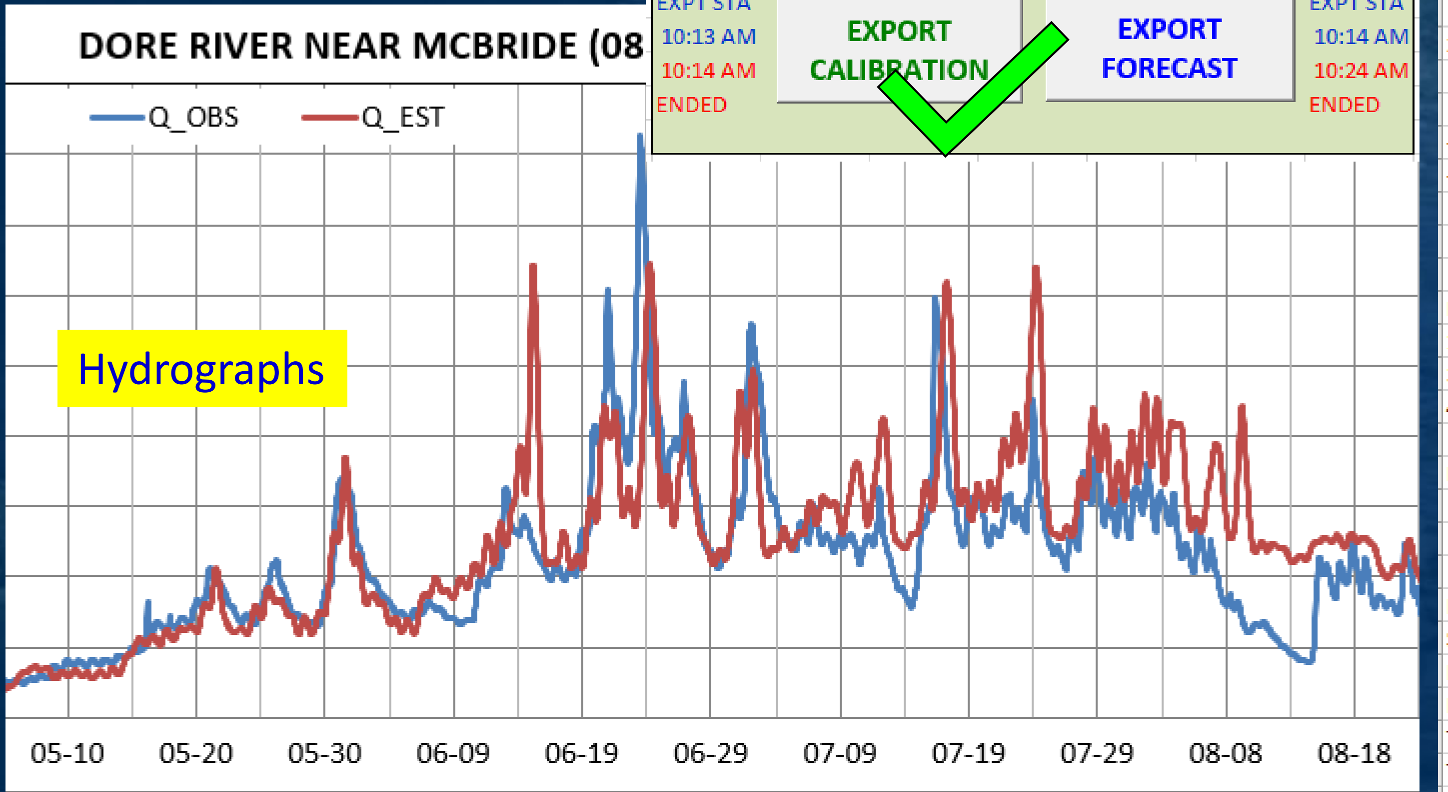
UPDATE DISCHARGE DATA ONLY

EXPT STA 10:13 AM 10:14 AM ENDED

EXPORT CALIBRATION

EXPORT FORECAST

EXPT STA 10:14 AM 10:24 AM ENDED




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| WATERSH | DORE RIVER NEAR MCBRIDE (08KA001) | | | | | | DORE |
| AREA (km | 407 | | DORE RIVER NEAR MCBRIDE (08 | | | WATERSH | Natural |
| AVERAGE | 1600 | | DORE RIVER NEAR MCBRIDE (08KA001) - HOURLY | | | | |
| | | | | | | | |
| STORAGE | 2.00 | CALCULATED FROM AREA AND FACTOR: 0.2 - 15 | | | | | |
| FACTOR T | 1.20 | CHANGE SHAPE OF HYDROGRAPH, GREATER, FLATTER | | | | | |
| HYDROGR | 1.00 | CHANGE PEAK OF HYDROGRAPH, GREATER, HIGHER | | | | | |
| FAST FLOV | 1 | 0 | 1 | 1- RUN GROUNDWATER MODEL | | | |
| BASE FLOV | 2 | | 0 | INITIAL GW STORAGE (mm) | | | |
| SOIL MOIS | 0.00 | | 1000 | MAX GW STORAGE (mm) | | | |
| INFILTRAT | 0.40 | | 200 | GW RELEASE THRESHOLD (m3/s) | | | |
| EVAPOTR | 0.05 | | 0.5 | RATE OF RELEASING (1/HOUR) | | | |
| SNOWME | 0.350 | 0.050 | 0.100 | MELT COEF CMD1, CMD2 (MAR/APR) | | | |
| SNOW ME | 0.75 | 0.200 | 05-21 | DATE OF STEADY SNOWMELT | | | |
| NUMBER ( | ID | WEIGHT | EL (m) | dTX_C | dTN_C | dP_mm | P_factor |
| 2 | MBP | 0.6 | 1611 | 0.0 | 0.0 | -4.0 | 1.00 |
| | MBH | 0.4 | 716 | 0.0 | 0.0 | -5.0 | 0.90 |
| | | | | | | | |
| <-GO TO MODEL FILE | | | | | | | |
| <-GO TO FIGURES SH | | | | | | RAINFALL | 1 |
| | NEW | OLD | | | | | |
| INITIAL SV | 1200 | 1200 | | | | | |
| | | | | dTX_C | dTN_C | dP_mm | |
| METHOD OF EXTENDING TO 10 | | | 1 | 0.0 | 0.0 | 0.0 | |
| 1 - STATIC (T&P AS LAST DAY)/2 | | | 1-THIS STN ONLY | | | | |
| 3 - FLAT WITH INCREMENT AS S | | | 2-ALL SUB BASINS | | | | |
| 4 - LINEAR WITH UNIFORM SLO | | | 3-DOWSTREAM | | | | |
| | | | 4-ENTIRE GROUP | | | 1 | |
| RIVER ROU | 1 | (1-CHANNEL, 2-LAKE) | | | ADDITIONAL INFLOWS FOR LAK | | |
| | dX(Km) | dT(s) | dX/dT | | | | |
| | 8 | 3600 | 2.222 | | | | |
| FLOW GAU | 750 | | 1 - RE-LOAD | | | | |
| DISTANCE | 16 | | INPUT FILES | | | | |
| SLOPE (S0 | 0.053125 | | BLANK(DEFAULT) - | | | | |
| MANNING | 0.12 | | NOT RE-LOAD INPUT FILES | | | | |
| RIVER WID | 40 | | | | | | |
| TOTAL NU | 2 | | | | | FORECAST | 100 |
| TOTAL NU | 720 | | | | | Linear Hou | 12 |

Model parameters

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RIVER FORECAST CENTRE
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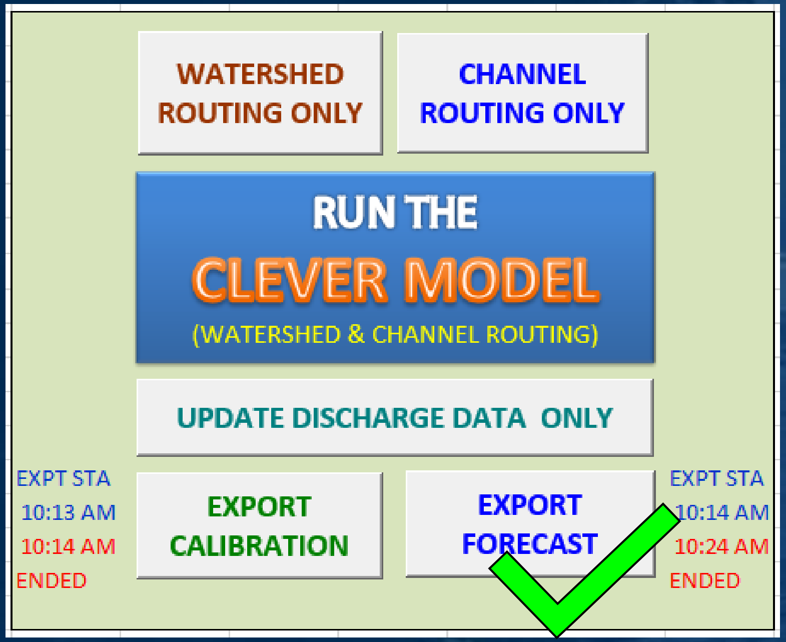
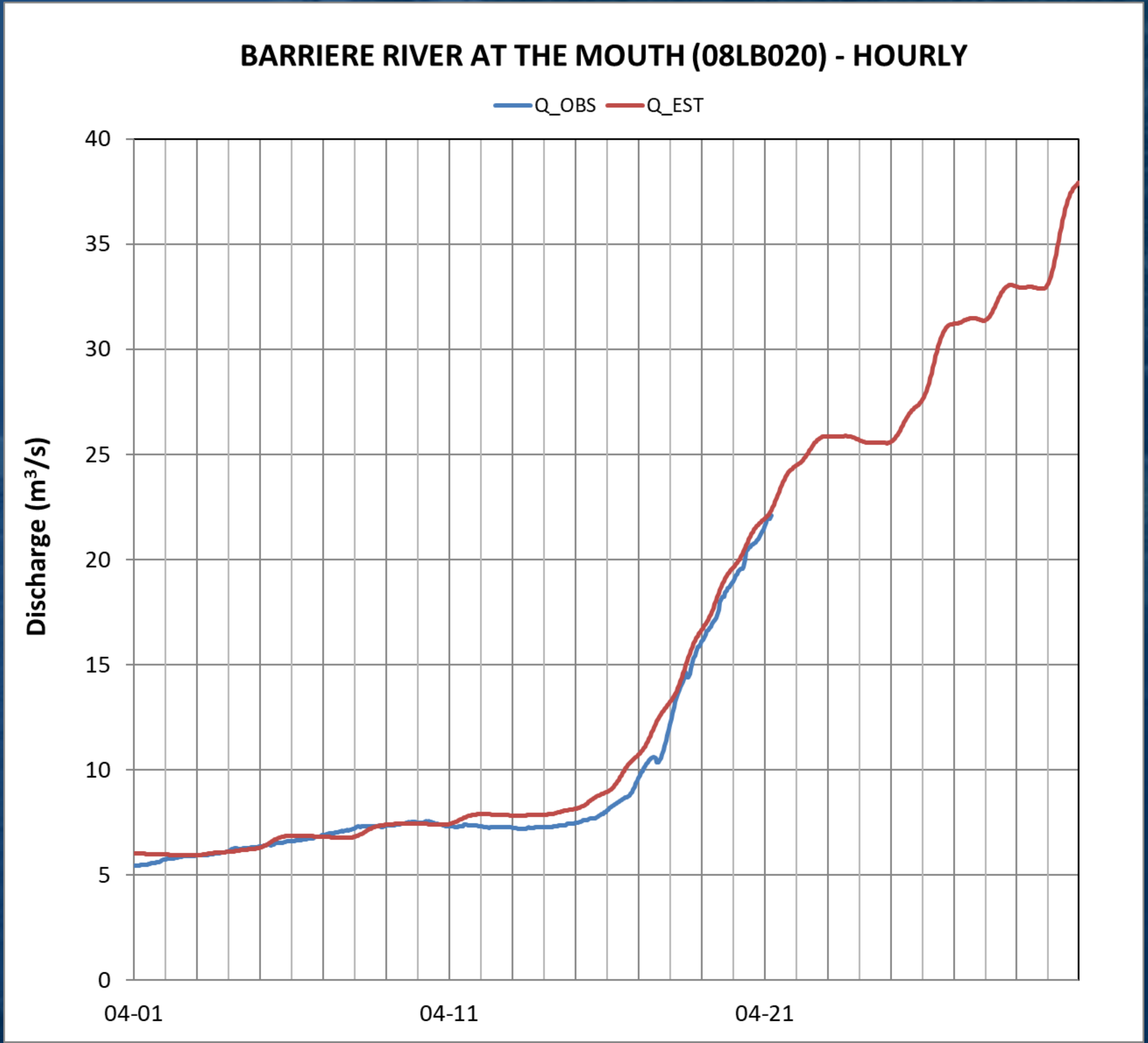
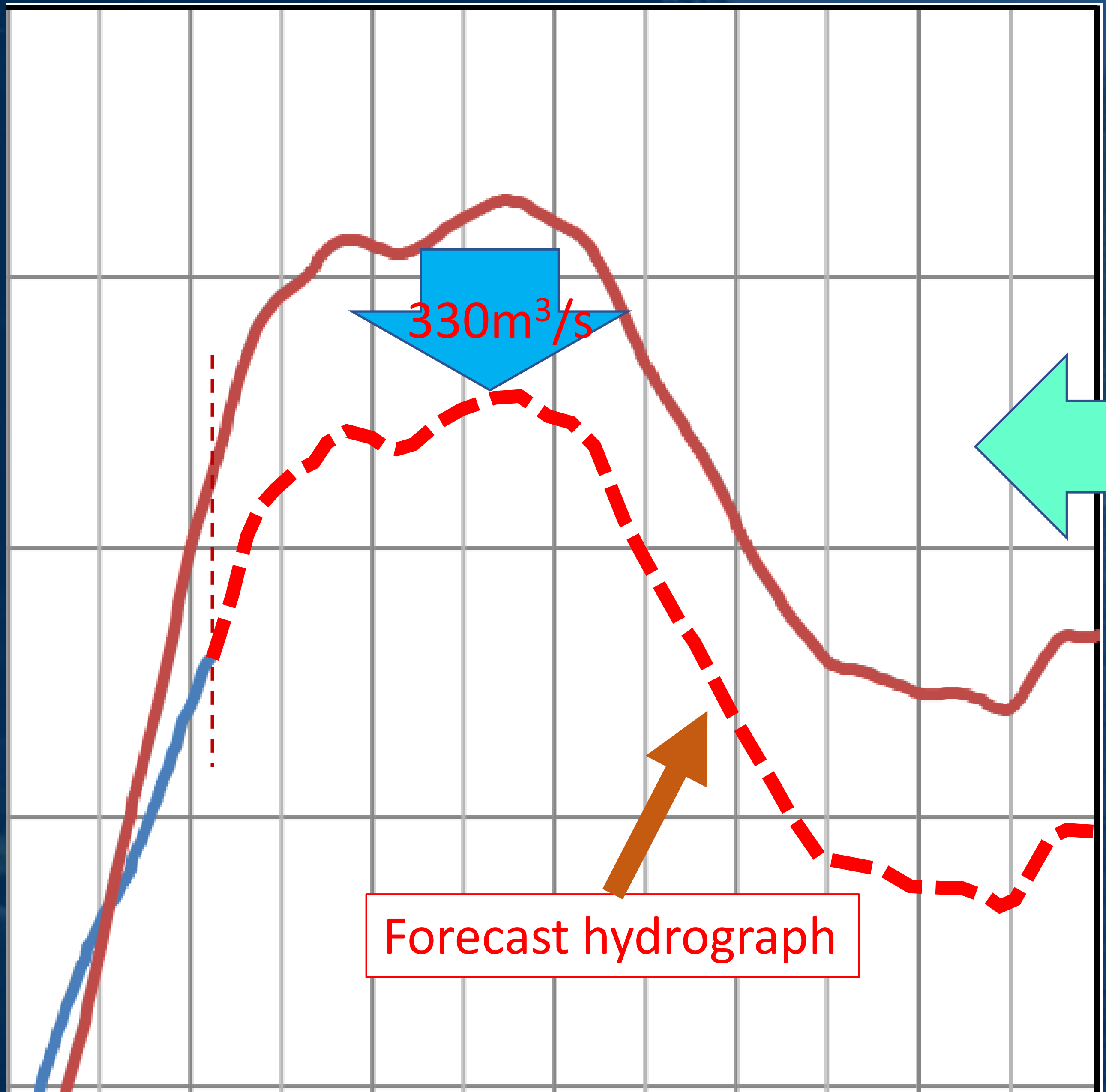
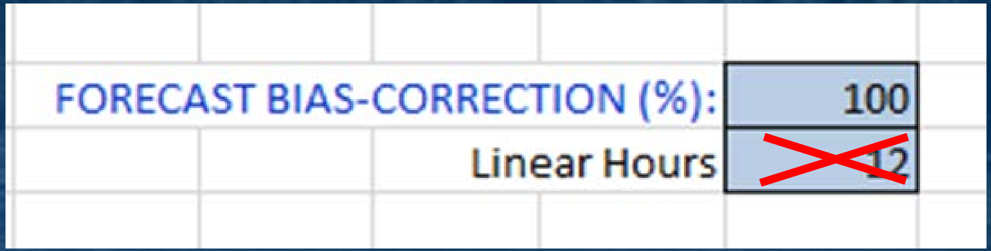
# 8. Producing forecasts – informative and easy to read



# 8. Producing forecasts – informative and easy to read



| | |
|---|---|
| FORECAST BIAS-CORRECTION (%): | 100 |
| Linear Hours | ~~12~~ |

# 9. Model history – developing, expanding and upgrading

## The Channel Links Evolution Efficient Routing (CLEVER) Model

| | | |
|---|---|---|
| 2013 | Planning, researching and coding the first version of the CLEVER Model(M) | 32 stn |
| 2014 | Test running the CLEVER Model (Moderate water year) | 51 stn |
| 2015 | **Starting operational running the CLEVER Model** (Low water year) | 71 stn |
| 2016 | Operational running the CLEVER Model (Very low water year) | 74 stn |
| 2017 | Significant increase of modeled stations (Moderate water year) | 102 stn |
| 2018 | Operational running the CLEVER Model (High water year) | 108 stn |
| 2019 | Providing CSV files of hourly forecast for users to download (Low water y) | 119 stn |
| 2020 | Significant expanding modeling scope (Extensive flooding year) | **266 stn** |
| 2021 | **1. Massive upgrading, including feature allowing multi-users to run the model in parallel to improve time efficiency.** **2. First paper about the CLEVER Model published in an international peer reviewed journal (J. Hydro. Eng., ASCE)** | **311 stn** |

RIVER FORECAST CENTRE BUSINESS TRANSFORMATION
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# 10. Post freshet review of model performance

– statistics and flooding events

## Statistic analysis:

Coefficient of model efficiency ($C_e$)

$$C_e = 1 - \frac{\sum_{j=1}^{m}\left(Q_{obs}^{j} - Q_{sim}^{j}\right)^2}{\sum_{j=1}^{m}\left(Q_{obs}^{j} - \overline{Q_{obs}}\right)^2}$$

$$\overline{Q_{obs}} = \frac{1}{m}\sum_{j=1}^{m} Q_{obs}^{j}$$

$$\overline{Q_{sim}} = \frac{1}{m}\sum_{j=1}^{m} Q_{sim}^{j}$$

$$\overline{Q_{sim}^2} = \frac{1}{m}\sum_{j=1}^{m} \left(Q_{sim}^{j}\right)^2$$

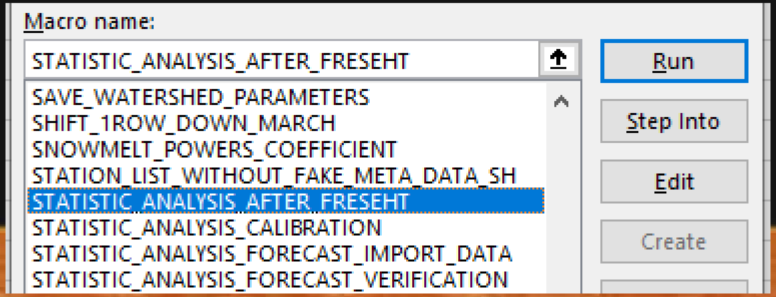
$$\overline{Q_{obs}^2} = \frac{1}{m}\sum_{j=1}^{m} \left(Q_{obs}^{j}\right)^2$$

### Statistic analysis for model calibration

Coefficient of determination ($C_d$)

$$\begin{cases} C_d = 1 - \dfrac{\sum_{j=1}^{m}\left[Q_{obs}^{j} - \left(a \cdot Q_{sim}^{j} + b\right)\right]^2}{\sum_{j=1}^{m}\left(Q_{obs}^{j} - \overline{Q_{obs}}\right)^2} \\ a = \left(\bar{P} - \overline{Q_{obs}} \cdot \overline{Q_{sim}}\right) / \left(\overline{Q_{sim}^2} - \overline{Q_{sim}}^2\right) \\ b = \overline{Q_{obs}} - a \cdot \overline{Q_{sim}} \end{cases}$$

$$\bar{P} = \frac{1}{m}\sum_{j=1}^{m}\left(Q_{obs}^{j} \cdot Q_{sim}^{j}\right)$$




Percentage volume difference ($dV$)

$$dV = 100 \times \left(\overline{Q_{sim}} - \overline{Q_{obs}}\right) / \overline{Q_{obs}}$$

### Statistic analysis for forecasts

Relative mean absolute error ($E_{ra}$)

$$E_{ra} = 100 \times \left(\frac{1}{m}\sum_{j=1}^{m}\left|Q_{sim}^{j} - Q_{obs}^{j}\right|\right) / \overline{Q_{obs}}$$

r squared ($r^2$)

$$r^2 = \frac{\left[\sum_{j=1}^{m}\left(Q_{obs}^{j} - \overline{Q_{obs}}\right)\left(Q_{sim}^{j} - \overline{Q_{sim}}\right)\right]^2}{\sum_{j=1}^{m}\left(Q_{obs}^{j} - \overline{Q_{obs}}\right)^2 \sum_{j=1}^{m}\left(Q_{sim}^{j} - \overline{Q_{sim}}\right)^2}$$

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# 10. Post freshet review of model performance

## – statistics and flooding events

## After freshet review (AFR) reports as of 2017:

After Freshet Review (AFR) of
CLEVER Model Performance in 2020

Charles Luo, Ph.D., P.Eng.
BC River Forecast Centre
March 2021

Citing this document:
Luo, C., 2021. After Freshet Review (AFR) of CLEVER Model Performance in 2020. Technical Report of BC River Forecast Centre, Victoria, BC.

CLEVER Model after Freshet Review (AFR) 2017

Charles Luo, August 2017

CLEVER Model after Freshet Review (AFR) 2018

Charles Luo, September 2018

CLEVER Model after Freshet Review (AFR) 2019

Charles Luo
November 2019



1. Changes of modeling scope
2. Statistics of model calibration and forecasts
3. Model performance during flooding events
4. Recommendations for model improvements

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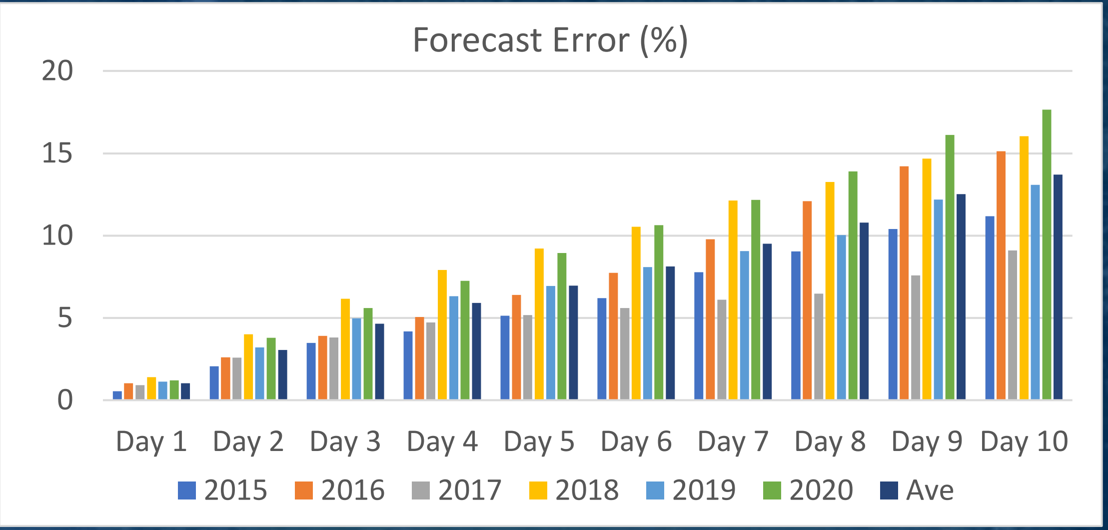
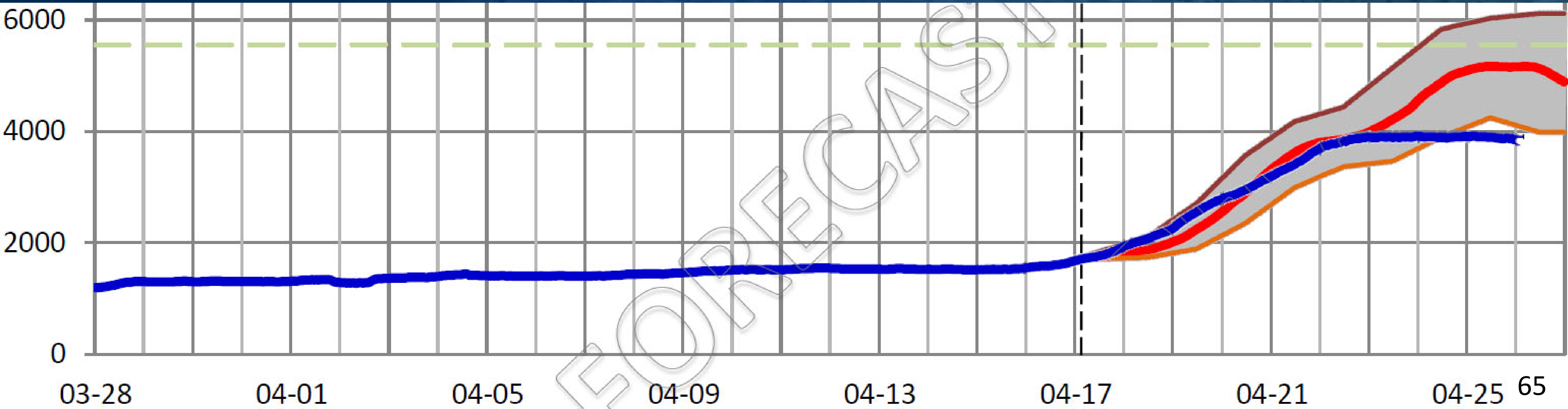
# 10. Post freshet review of model performance

## – statistics and flooding events

### Forecast errors of FRASER RIVER AT HOPE (08MF005)

| Year | Forecast Error (%) | | | | | | | | | | Statistics | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Day 9 | Day 10 | AveErr | RSQU |
| 2015 | 0.6 | 2.1 | 3.5 | 4.2 | 5.1 | 6.2 | 7.8 | 9.0 | 10.4 | 11.2 | 6.0 | 0.738 |
| 2016 | 1.0 | 2.6 | 3.9 | 5.1 | 6.4 | 7.7 | 9.8 | 12.1 | 14.2 | 15.1 | 7.8 | 0.444 |
| 2017 | 0.9 | 2.6 | 3.8 | 4.7 | 5.2 | 5.6 | 6.1 | 6.5 | 7.6 | 9.1 | 5.2 | 0.772 |
| 2018 | 1.4 | 4.0 | 6.2 | 7.9 | 9.2 | 10.5 | 12.1 | 13.3 | 14.7 | 16.0 | 9.5 | 0.606 |
| 2019 | 1.1 | 3.2 | 5.0 | 6.3 | 6.9 | 8.1 | 9.1 | 10.0 | 12.2 | 13.1 | 7.5 | 0.554 |
| 2020 | 1.2 | 3.8 | 5.6 | 7.3 | 8.9 | 10.6 | 12.2 | 13.9 | 16.1 | 17.6 | 9.7 | 0.497 |
| Ave | 1.0 | 3.0 | 4.7 | 5.9 | 7.0 | 8.1 | 9.5 | 10.8 | 12.5 | 13.7 | 7.6 | 0.602 |

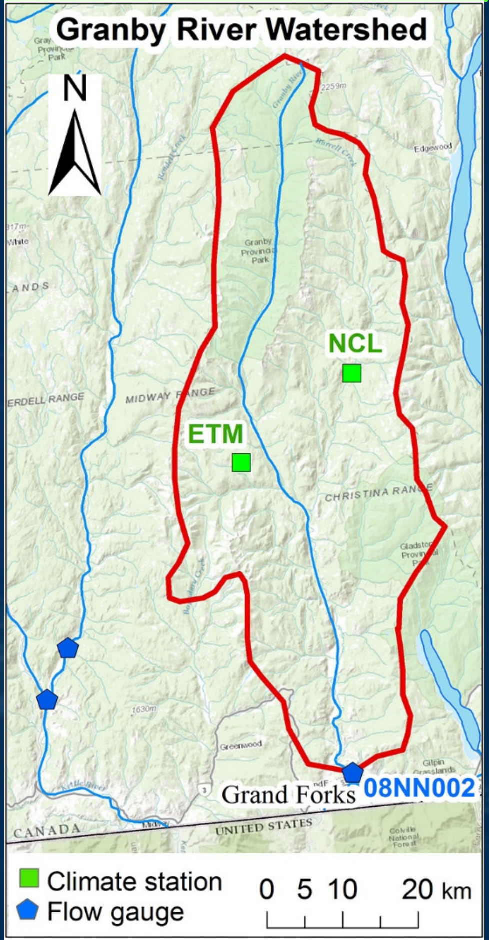


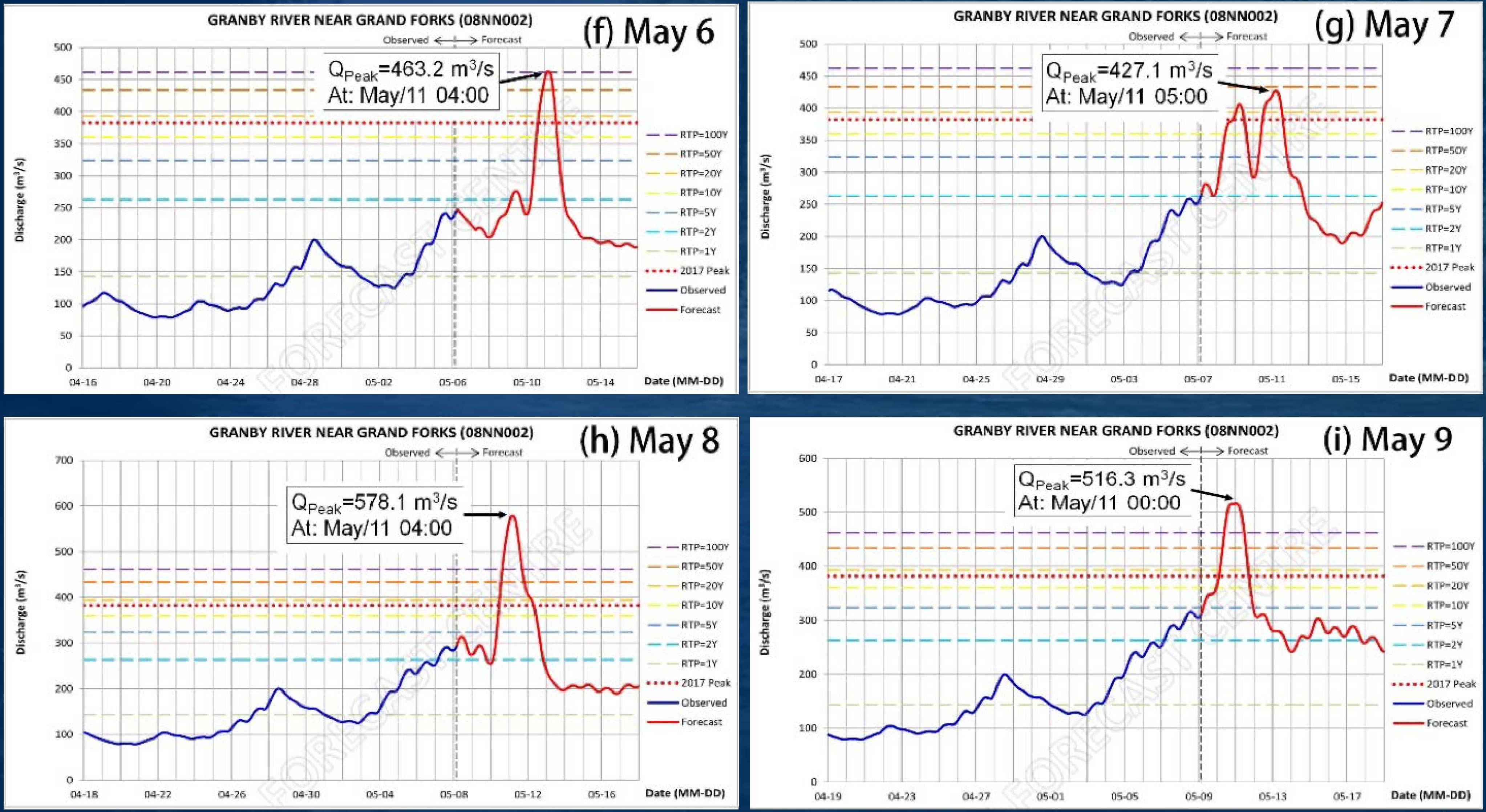



# 10. Post freshet review of model performance

– statistics and flooding events

**Review of Granby May 10, 2018 Flood (3:55 p.m. PST) (Observed Q peak = 524 m³/s)**



# 10. Post freshet review of model performance

– statistics and flooding events

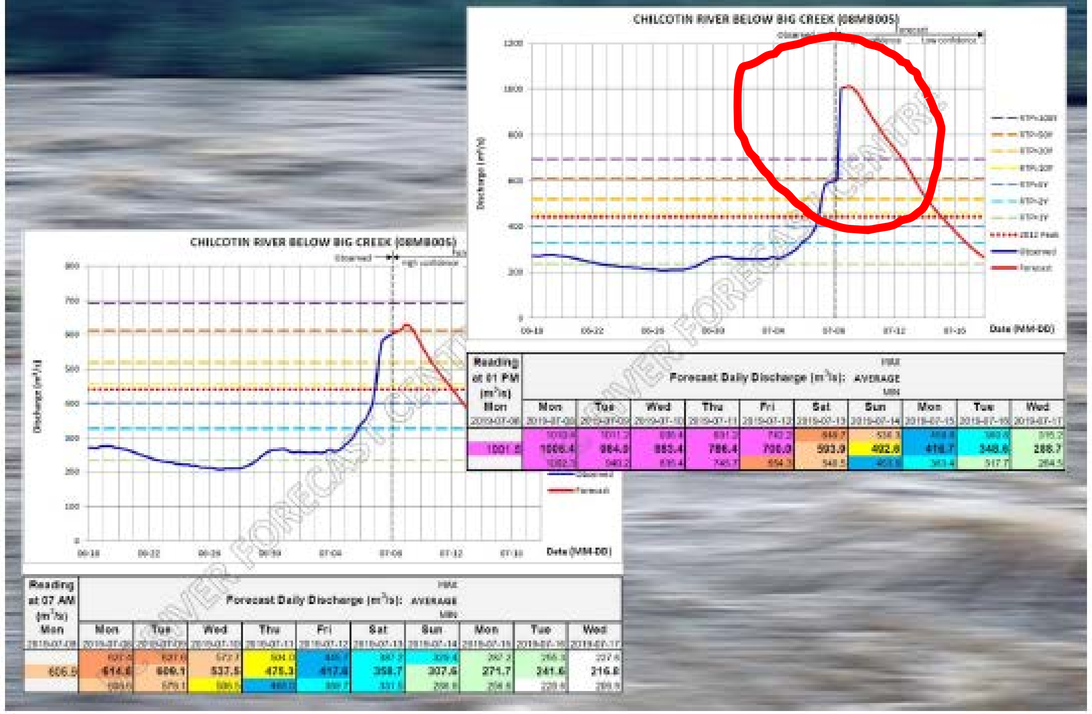
(78 pages) British Columbia River Forecast Centre

## Review of Early July 2019 Chilcotin River Flood from Perspective of Hydrologic Modeling Efforts

Charles Luo, Ph.D., P.Eng.

River Forecast Centre, May 2020

http://bcrfc.env.gov.bc.ca/freshet/cleverm_ref/ChilcotinFlood2019July_lr.pdf



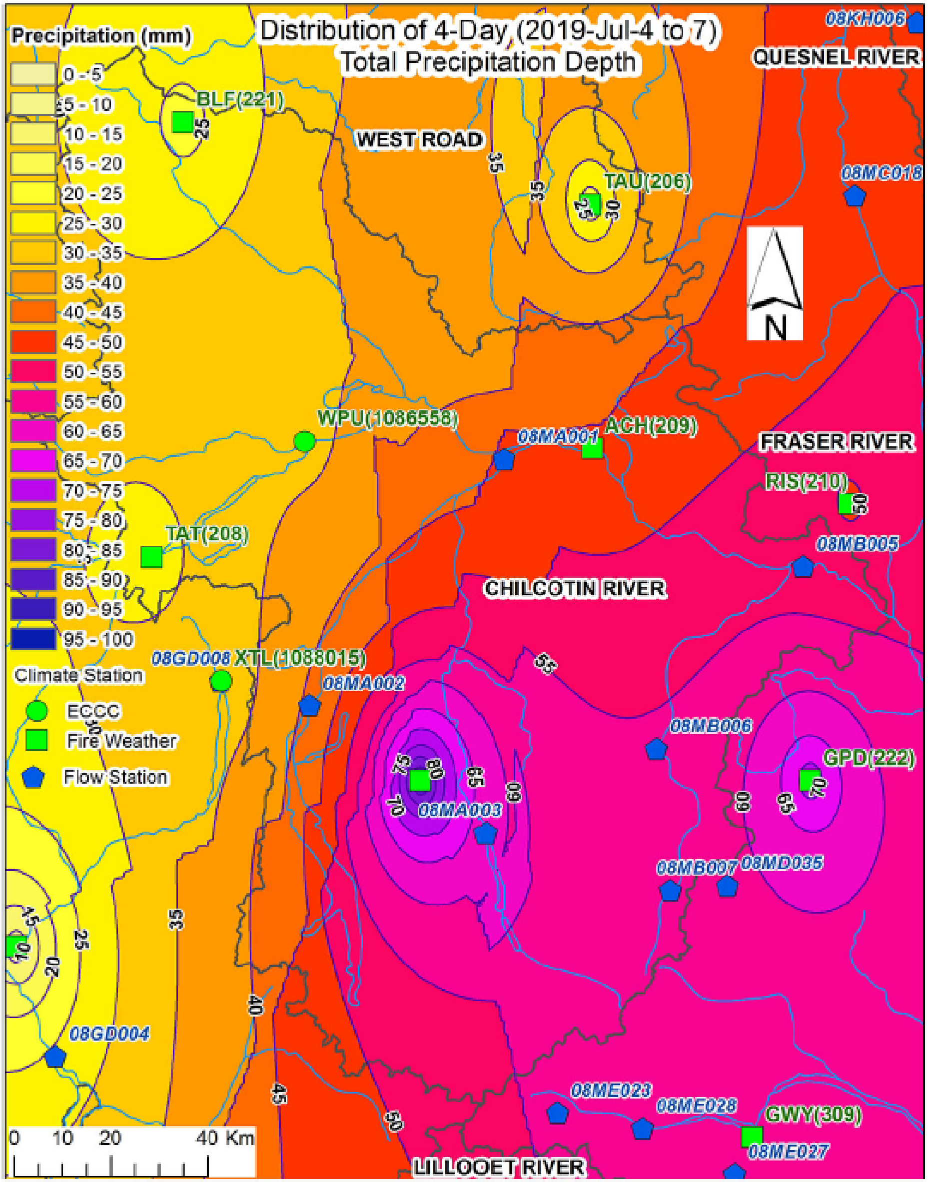
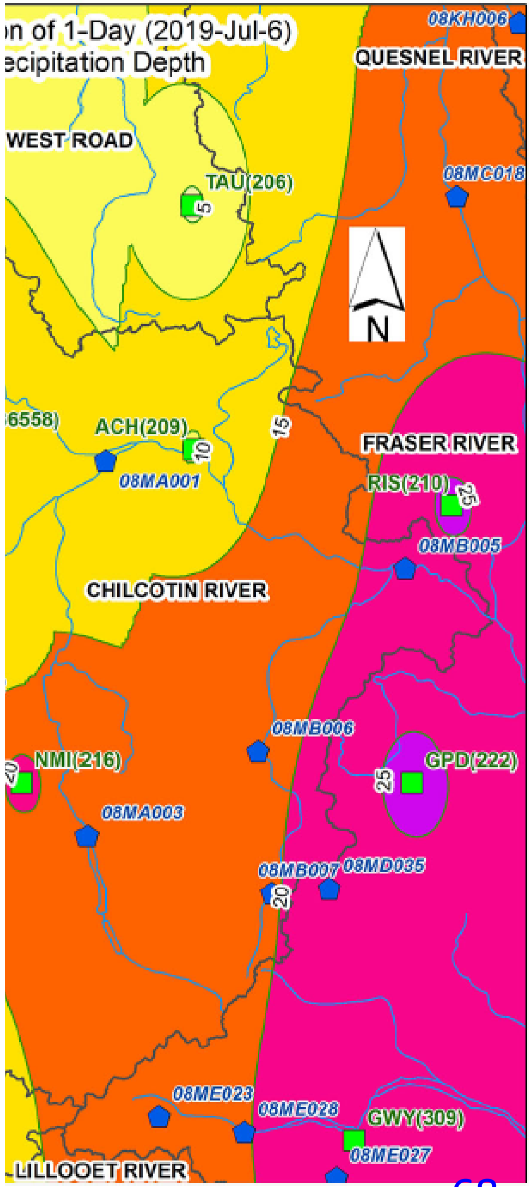




Figure 8. Isohyet map of 4-day (July 4 to 7, 2019) total precipitation depth in Chilcotin River watershed




n depth in Chilcotin River watershed, July 6, 2019

# 11. Modeling uncertainties – understanding limitations

First category of modeling uncertainties coming input data

- Forecast climate data (ECCC CMC NWP Grib2 Regional MD 10km/ global MD 25km) and downscaling to clim. st
- Observed climate data: missing and interpolation/ extrapolation
- Observed flow data: gauge issues and missing data

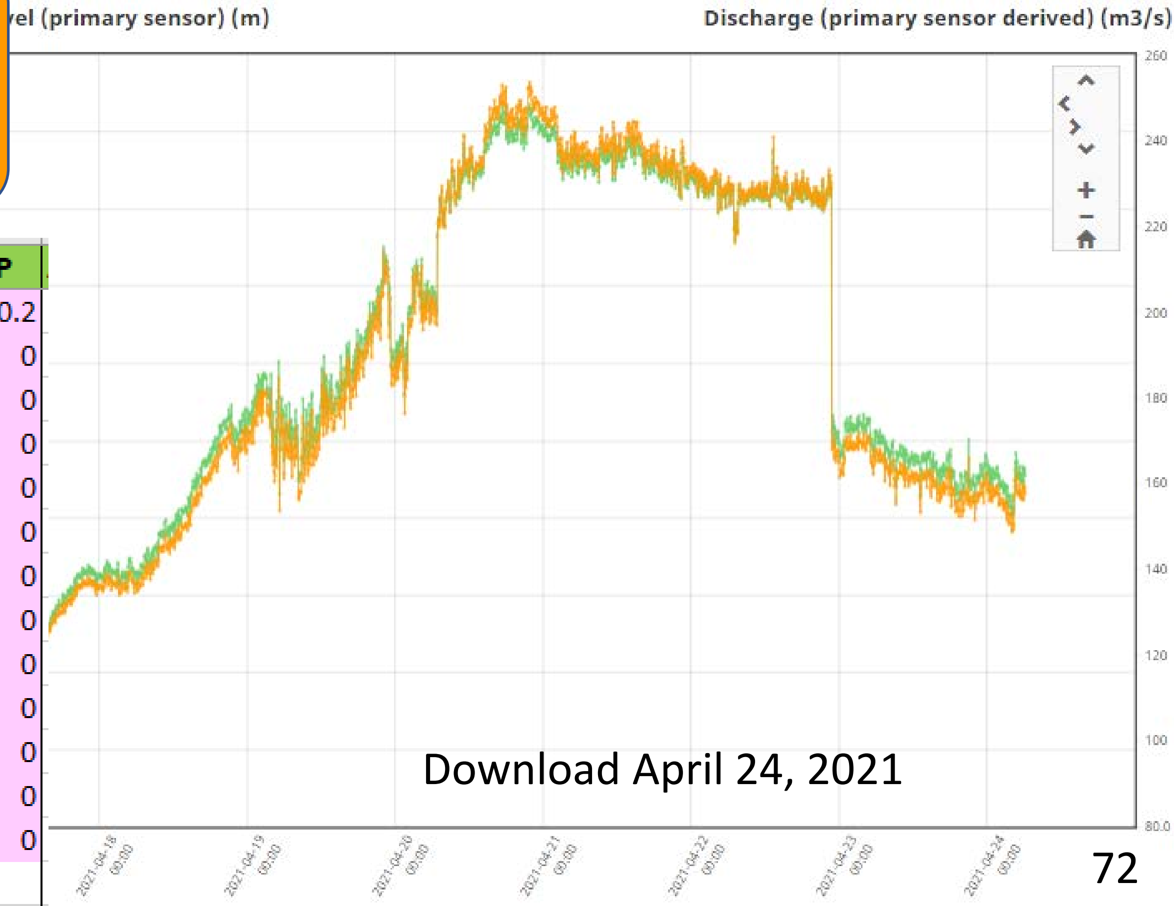
| DATE | CHP-TX | CHP-TN | CHP-PP | SPZ-TX | SPZ-TN | SPZ-PP | MTC-TX | MTC-TN | MTC-PP |
|---|---|---|---|---|---|---|---|---|---|
| 2021-04-10 | -4.6 | -6.6 | 0 | 5.2 | -3.1 | 13 | 3 | -4.8 | 0.2 |
| 2021-04-11 | -1.3 | -8.6 | 0 | 5.5 | -9.9 | 0 | 2.9 | -9.6 | 0 |
| 2021-04-12 | 7.5 | -5.7 | 0 | 4.8 | -7.1 | 0 | 5.6 | -8 | 0 |
| 2021-04-13 | 12.7 | -7.1 | 0 | 9.7 | -5.6 | 0 | 9.7 | -11.1 | 0 |
| 2021-04-14 | 17.9 | -4.6 | 0 | 14.1 | 0.4 | 0 | 16.2 | -9.3 | 0 |
| 2021-04-15 | 14.5 | -2.4 | 0 | 17.4 | [illegible] | 0 | 18.5 | -8.4 | 0 |
| 2021-04-16 | 16.9 | 6.5 | 0 | 19 | 2.3 | 0 | 19.5 | -7.6 | 0 |
| 2021-04-17 | 18.2 | 9 | 0 | [illegible] | 1.6 | 0 | 20.7 | -7.1 | 0 |
| 2021-04-18 | 13.3 | 8.2 | 0 | 17.3 | 1.1 | 0 | 9.3 | -6.3 | 0 |
| 2021-04-19 | 9.9 | 3.3 | [illegible] | [illegible] | 1.2 | 0 | 12.3 | -3.1 | 0 |
| 2021-04-20 | 11.9 | 4.8 | 0 | 16.4 | 0.2 | 0 | 15.9 | -9.2 | 0 |
| 2021-04-21 | 12.4 | 5.2 | 0 | 13.6 | -0.3 | 0 | 15.1 | -7.5 | 0 |
| 2021-04-22 | 8.2 | 2.1 | 0 | 12.6 | -0.7 | 0 | 7.6 | -1.5 | 0 |
| 2021-04-23 | | 0.2 | | | -1 | | | -7.8 | |

**Missing data**

## Real-Time Hydrometric Data Graph for WEST ROAD RIVER NEAR CINEMA (08KG001) [BC]

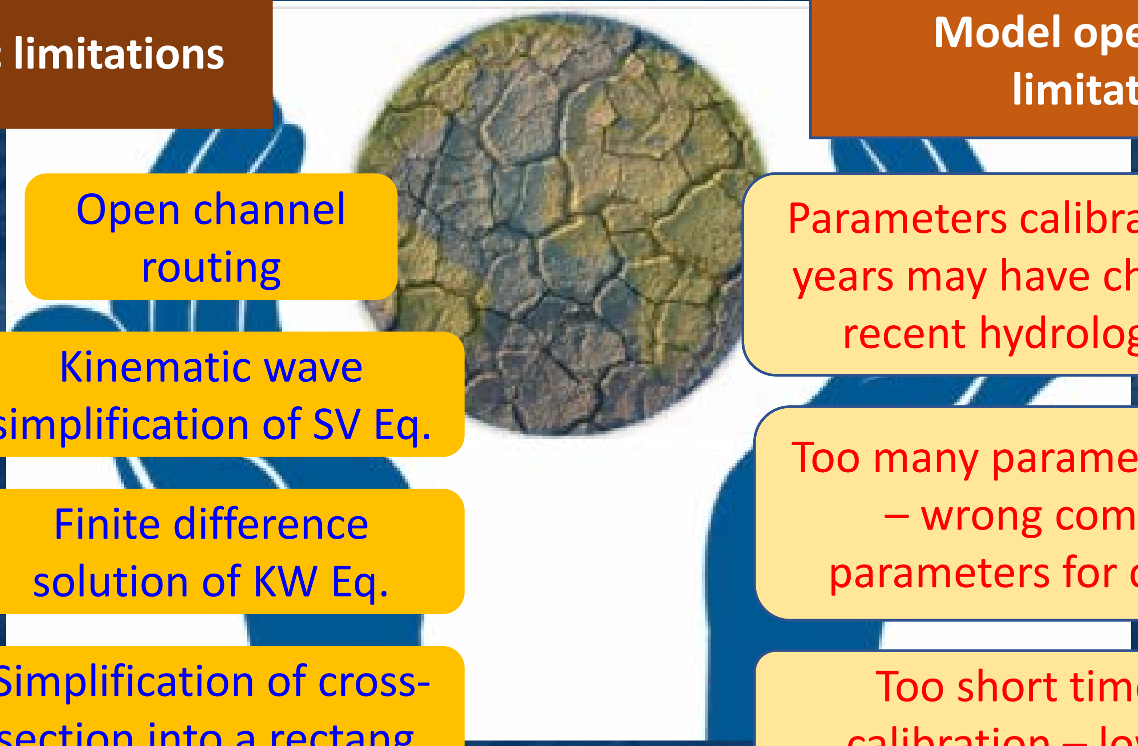
**Station Notice**

The regular flow measurement program at this hydrometric gauge is compromised because the cableway is currently out of service. Please email ec.shnhydrologiquebc-nhshydrologicalbc.ec@canada.ca with any questions or concerns.



# 11. Modeling uncertainties – understanding limitations

**Second category of modeling uncertainties coming from the model itself**



## Model intrinsic limitations

- Watershed routing
- Simplifying a basin into a single node
- Simplifying hydrologic cycle: Evp, Inf, GD, SM
- Lack of overland flow routing
- Using daily data to distribute into hourly

- Open channel routing
- Kinematic wave simplification of SV Eq.
- Finite difference solution of KW Eq.
- Simplification of cross-section into a rectang.
- Lack of data of channel dimensions (42,150 km)

## Model operational limitations

- Parameters calibrated in previous years may have changed without recent hydrologic indicators
- Too many parameters to calibrate – wrong combination of parameters for correct results
- Too short time for model calibration – lower accuracy
- Modelers’ experience

# 12. Types of modeled stations

FLOW STN

- WSC_ACTIVE
- WSC_INACTIVE
- NON_WSC
- ESTIMATED
- ROUTING

?

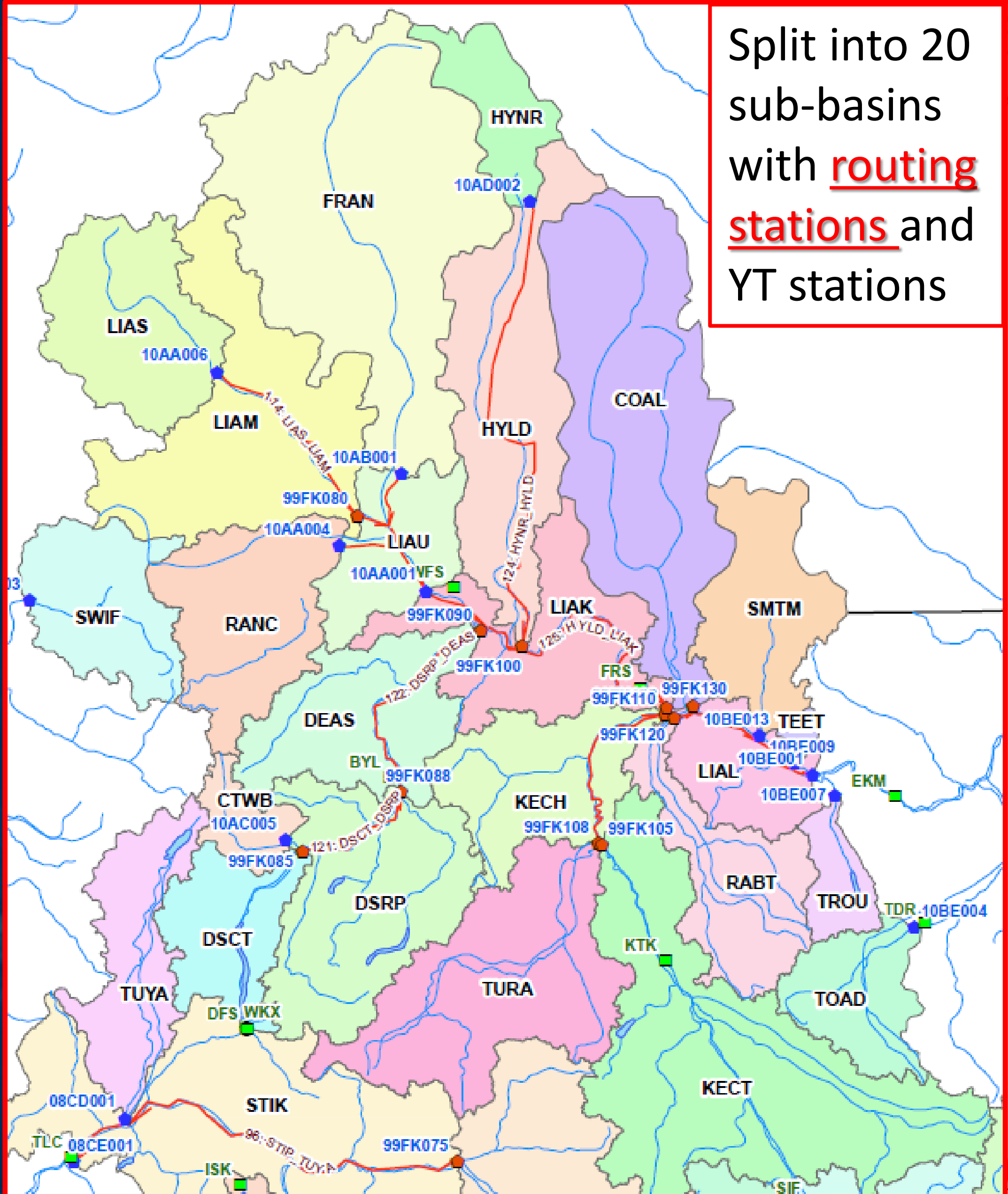
The only type of stations included in the model when developed and in early stage of operation (watersheds were split originally based on WSC stations)

1. After April 2018 West Road River/Nazko River flood, the inactive WSC station NAZKO RIVER ABOVE MICHELLE CREEK (08KF001) was added because of flooding concerns.
2. After July 2019 Chilcotin River Flood, WSC eliminated the CHILCOTIN RIVER BELOW BIG CREEK (08MB005), which was kept in the model as an inactive station for better model calibration.
3. PEACE RIVER AT HUDSON HOPE (07EF001) became inactive in 2019 and removed from the model in 2020. It was restored in the model as an inactive station in 2021 for better model calibration.
4. Because of flooding concerns, the SOMASS RIVER NEAR ALBERNI (INACTIVE STATION) (08HB017) was included when VI basins were included in the model as of 2020.

The only Non-WSC station is the LILLOOET RIVER FSR (08MG00A) (BC station ID: 08MG0001), an important station for Pemberton.

# 12. Types of modeled stations

Split into 20 sub-basins with routing stations and YT stations




Liard River, A=104,000 km²